GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 1/31/79

Project Title: Gravity Survey in the Vicinity of Proposed COCORP Traverse Across the Brevard Zone Near Gainesville, Georgia

Project No: G-35-648 Green Card

Project Director: Dr. A. M. Dainty

Sponsor: National Science Foundation, Washington, D. C. 20550

Agreement Period: From 12/15/78 Until 5/31/80*
*Includes 6 month flexibility period

Type Agreement: Grant No. EAR-7822056

Amount: $18,700 NSF Funds (G-35-648)
1,765 GIT Contribution (G-35-335)
$20,465 TOTAL

Reports Required:
Annual Progress Reports; Final Project Report

Sponsor Contact Person (s):

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Defense Priority Rating: n/a

Assigned to: Geophysical Sciences (School/Laboratory)

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CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 9/8/82

Project Title: Gravity Survey in the Vicinity of Proposed COCORP Traverse Across the Brevard Zone near Gainesville, GA.

Project No: G-35-648

Project Director: Dr. A. M. Dainty

Sponsor: National Science Foundation

Effective Termination Date: 5/31/80

Clearance of Accounting Charges: ____________________

Grant/Contract Closeout Actions Remaining:

NONE REMAINING

- [ ] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________________

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NOTE: Send to RAN & File only since this one is considered closed out by others and a new project with same number has been assigned. Should cause less confusion.

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PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION
Cover Page

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (Indicate the most specific unit known, i.e. program, division, etc.)
Geophysics Program, Earth Sciences Division

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? Yes ___ No X ; IF YES, LIST ACRONYM(S):

PROGRAM ANNOUNCEMENT/SOLICITATION NO.:
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NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)
Georgia Institute of Technology, Office of Contract Administration, Administration Building,

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE)
225 North Avenue, Atlanta, GA 30332

TITLE OF PROPOSED PROJECT
Gravity Survey in the Vicinity of Proposed COCORP Traverse across the Brevard Zone near Gainesville, Georgia (Renewal)

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
$37,103	18 Months	1 July 1980

PI/PD DEPARTMENT	PI/PD ORGANIZATION	PI/PD PHONE NO.
Geophysical Science	Georgia Institute of Technology	(404)894-2860

PI/PD NAME	SOCIAL SECURITY NO.*	DATE OF HIGHEST DEGREE ACHIEVED	MALE*	FEMALE*
Dr. Anton M. Dainty	012-48-8880	1967	X	
ADDITIONAL PI/PD: Dr. Leland T. Long	126-32-0315	1968	X	
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				

FOR RENEWAL OR CONTINUING AWARD REQUEST, LIST PREVIOUS AWARD NO.: EAR-7822056

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- ☐ Research Involving Recombinant DNA Molecules
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- ☐ Pollution Control
- ☐ Proprietary and Privileged Information

	PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	AUTHORIZED ORGANIZATIONAL REP.	OTHER ENDORSEMENT (optional)
NAME	Dr. Anton M. Dainty	Phyllis R. Oliver	Dr. Charles E. Weaver
SIGNATURE			
TITLE	Associate Professor	Contracting Officer	Director, School of Geophysical Sciences
DATE	2/4/80	2/4/80	

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SMITHSONIAN INSTITUTION

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PROJECT SUMMARY

PROJECT NO. (Do not use this space)
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1. NAME OF INSTITUTION (INCLUDE BRANCH/CAMPUS & SCHOOL OR DIVISION)

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3. PRINCIPAL INVESTIGATOR AND FIELD OF SCIENCE/SPECIALTY

Dr. Anton M. Dainty, Geophysics

4. TITLE OF PROJECT

Gravity Survey in the Vicinity of Proposed COCORP Traverse across the Brevard Zone near Gainesville, Georgia

5. SUMMARY OF PROPOSED WORK (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES)

An extension of our previous gravity survey over the Brevard Zone and the COCORP line across the Brevard is proposed to the southeast. The proposed survey will examine structures along and near the COCORP line, specifically two granitic plutons, the Elberton granite (350 m.y. old) and the Danburg granite (265 m.y. old). Both of these plutons are late intrusives and cross-cut the structural trends of the Appalachian system. Their structural setting should provide close constraints on the timing and nature of any thrust-faulting in this part of the system.

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DIVISION (OFFICE) AND DIRECTORATE	PROGRAM	
SECTION	PROPOSAL NO.	F.Y.

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START AND END DATES	AMOUNT GRANTED

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PROJECT DESCRIPTION

Introduction

The tectonics of the Appalachian system are a subject of continuing study and controversy (compare, for example, Hatcher, 1972, and Rankin, 1975). Last year an important new piece of geophysical data was obtained, the COCORP seismic reflection traverse across the Appalachian system from the Valley and Ridge province of Tennessee to the Carolina Slate Belt of northeastern Georgia (Cook et al., 1979a, b). Cook et al. suggest, on the basis of their results, that thrusting has played a more important role in Appalachian tectonics than is generally recognised. Specifically, they consider that the crystalline Piedmont, including the inner Piedmont and apparently the Kings Mountain and Charlotte Belts, together with the Blue Ridge and the Valley and Ridge Provinces form a single large thrust sheet that has been thrust at least 200 km to the northwest. We propose to examine this conclusion.

An understanding of the timing of metamorphic, intrusive and faulting events is essential to this proposal, and accordingly a brief summary is given here. Several episodes of metamorphism have occurred in the Blue Ridge and Piedmont provinces, but it is generally held that metamorphism reached a climax about 400 million years (m.y.) ago (Hatcher, 1972; Fullager and Dietrich, 1976). From about 350 m.y. - 250 m.y. ago, intrusive plutons that cross-cut structural trends were emplaced (Fullager and Butler, 1979; Whitney et al., 1976; Kish, 1977). Faulting may have occurred on the Brevard fault, which is interpreted as a splay off the main thrust by Cook et al. (1979a, b) as early as Devonian time (see Stirewalt and Dunn, 1973, for a review), but the involvement of Pennsylvanian sediments in the Valley and Ridge province in thrusting indicates that movement on Cook et al's proposed thrust must have occurred as late as 300 m.y. ago and probably later. Another important piece of evidence on the age of movement of the proposed sole fault are the structural features of the Palmetto Granite, a cross-cutting pluton directly abutting the Brevard fault just south of Atlanta, Georgia (Higgins, 1968). This granite is in fault contact with country rocks to the northwest at the Brevard fault (Higgins, 1968), indicating that movement on the Brevard Fault postdates the emplacement of the granite. Unfortunately, there are no published age dates for the Palmetto Granite that the authors are aware of, but since it cross-cuts structural trends and is unmetamorphosed it presumably belongs to the late (350-250 m.y. age) episode of intrusion. Thus the proposed thrusting is at least in part a late phase in the tectonic history of the Appalachians.

A crucial question in the light of the proposed model of Cook et al. (1979a, b) is the strcutural relationship of the cross-cutting intrusive plutons to the presumed thrust fault. Cook et al. considered the plutons to be allochthonous; on this interpretation the plutons should not extend downwards through the plane of the proposed thrust (Note the discussion on the Palmetto Granite above.) We propose to examine this question.

Summary of Previous Work under this Grant

Work has been underway since December 15, 1978 on the collection of gravity data in area A of Figure 1. About 1200 stations have been occupied as of January 1. We anticipate that an additional 600 stations

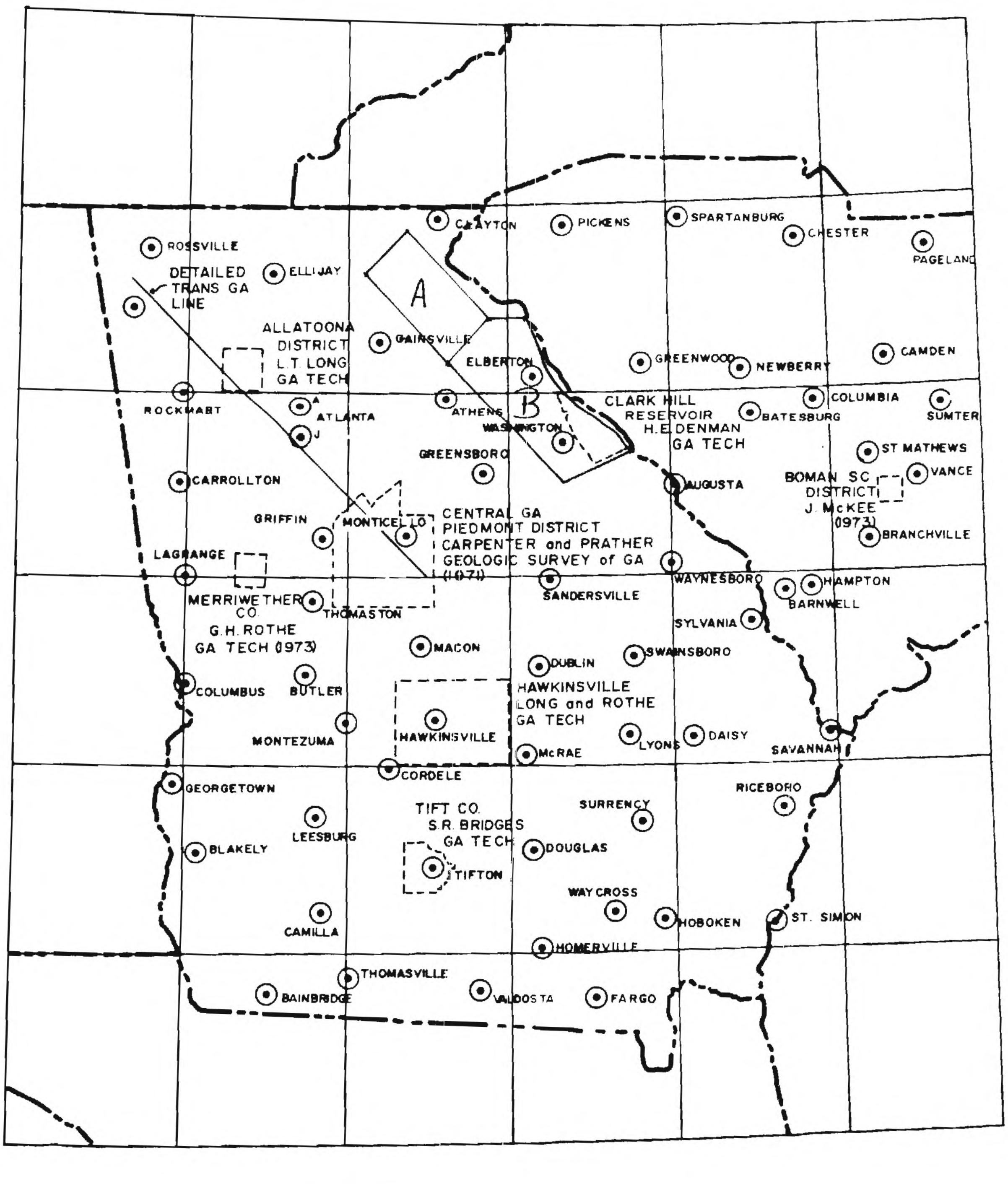

Figure 1. Base station, area surveyed under the present contract (area A), proposed survey area (area B) and location of other detailed surveys in Georgia and South Carolina. After Long (1974).

will be occupied over the next 6 months to complete the survey of area A. Figure 2 is a preliminary contour map of Bouguer gravity based on the stations occupied so far. Major regional features seen on the map include a strong decrease in Bouguer gravity in the southern part of the map going from southeast to northwest, known as the Piedmont Gravity Gradient, and a decrease of Bouguer gravity in the northern part of the map going from southwest to northeast, culminating in an intense (-60 mgal) low in the extreme northeast corner of the map. The Piedmont gravity gradient is due in this region to crustal thickening to the northwest (Long, 1979; Obaoye, 1979); this thickening, however, occurs about 70 km southeast of the Brevard Zone, which is indicated on Figure 2 and is a complex Zone of folding and shearing with thrusting to the northwest. The low in the northeast corner appears to be associated with the Tallulah Falls Dome and other structures to the north.

The main target area of this investigation was the Brevard Zone. There appears to be a slight negative anomaly of up to -3 mgals associated with the surface trace of the zone, as shown by the "nose" in the gravity contours of Figure 2. Figure 3 is a profile along line A B in Figure 2. This profile is close to the COCORP line 1 in Georgia, also marked, where stations are spaced at about 1000 foot intervals. As seen in Figure 3, there is an anomaly of approximately -1 to -2 mgal associated with the Brevard Zone. The estimated accuracy of the readings is $\pm$ 0.4 mgal, mainly because of inaccuracies in elevation, which is measured from Topo sheets. The small size of this anomaly indicates the the Brevard Zone does not separate rocks of substantially different nature in this region, in agreement with the findings of COCORP. The association of the anomaly with the surface trace of the

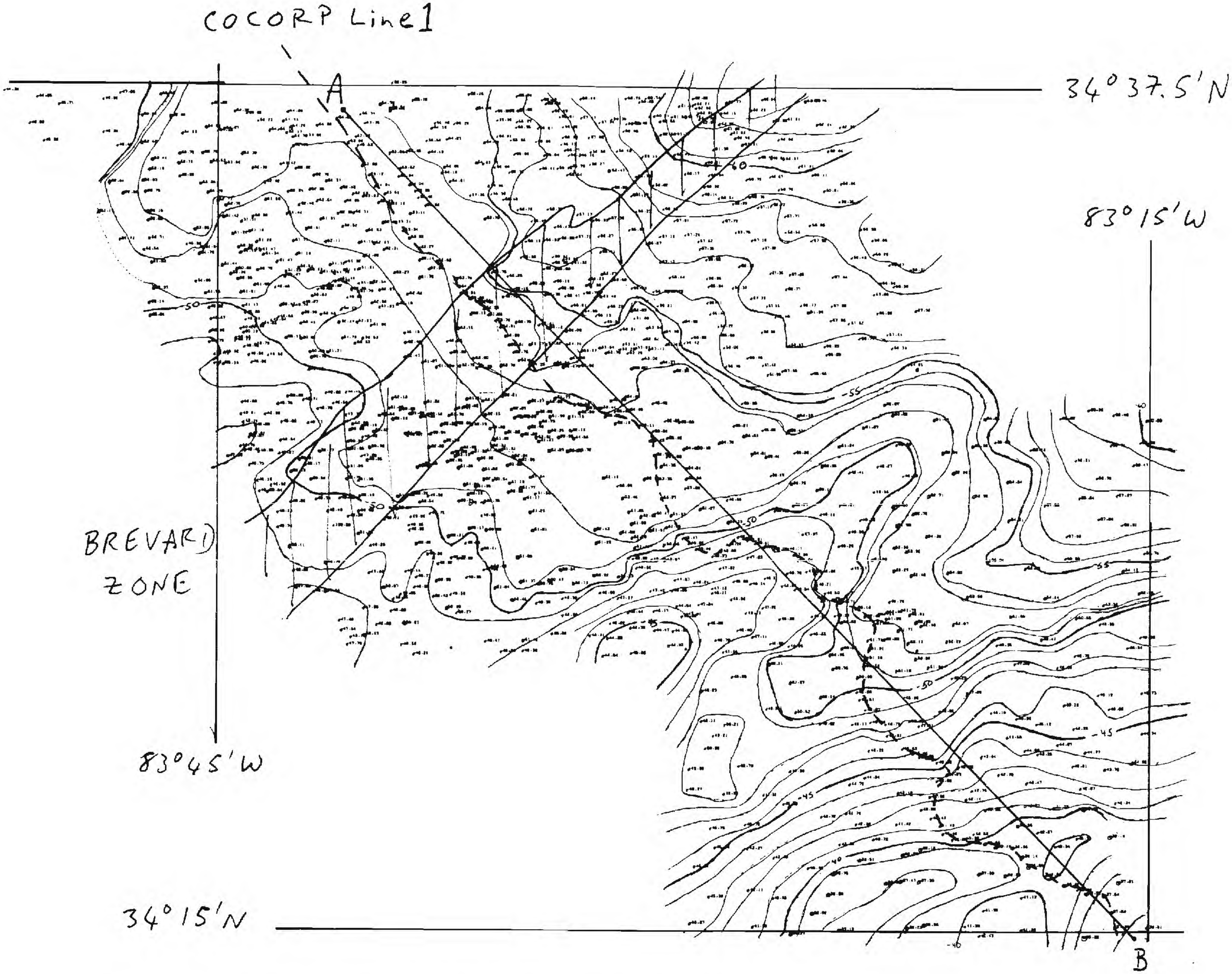

Figure 2. Preliminary map of simple Bouguer gravity based on work under this contract. Contour interval is one milligal.

Brevard Zone may be due to a slightly lesser density of the cataclastic rocks of the Brevard Zone compared to the surrounding rocks, or to greater weathering of the Brevard Zone comapred to surrounding rocks. The possibility of greater weathering in the Brevard Zone is strongly supported by geomorphic evidence - the Brevard Zone is a topographic low in this region, and the course of the Chattahoochee is directed along it from the study area to the Georgia - Alabama border to the southwest. The observed anomaly would be explained if the weathered layer were up to a few tens of meters thicker in the Brevard Zone than in the surrounding area. At the present stage of the investigation, we can offer no interpretation of subsurface structure of the Brevard Zone; this question will be examined over the next six months.

The work proposed in this renewal request is an extension southeastwards of the data base to examine structures along the continuation of the COCORP line to the southeast, and specifically two late granitic plutons (the Elberton granite and the Danburg granite) that cross-cut structural trends. The structural relations of these plutons to the proposed sole thrust of Cook _et al_. (1979a, b) promises to give considerable insight into the tectonics of the area. Because the granitic rocks are usually of lesser density than the surrounding country rocks, considerable structural information should be contained in the gravity field.

Proposed Work, Justification and Anticipated Problems

We propose a detailed gravity survey (1/2 to 2 km spacing) of area B in Figure 1. Figure 1 also shows base stations and other surveys in the area, specifically the work of Denman and others (Denman, 1975; Long _et al_., 1976), who obtained about 1400 stations to the south of area B.

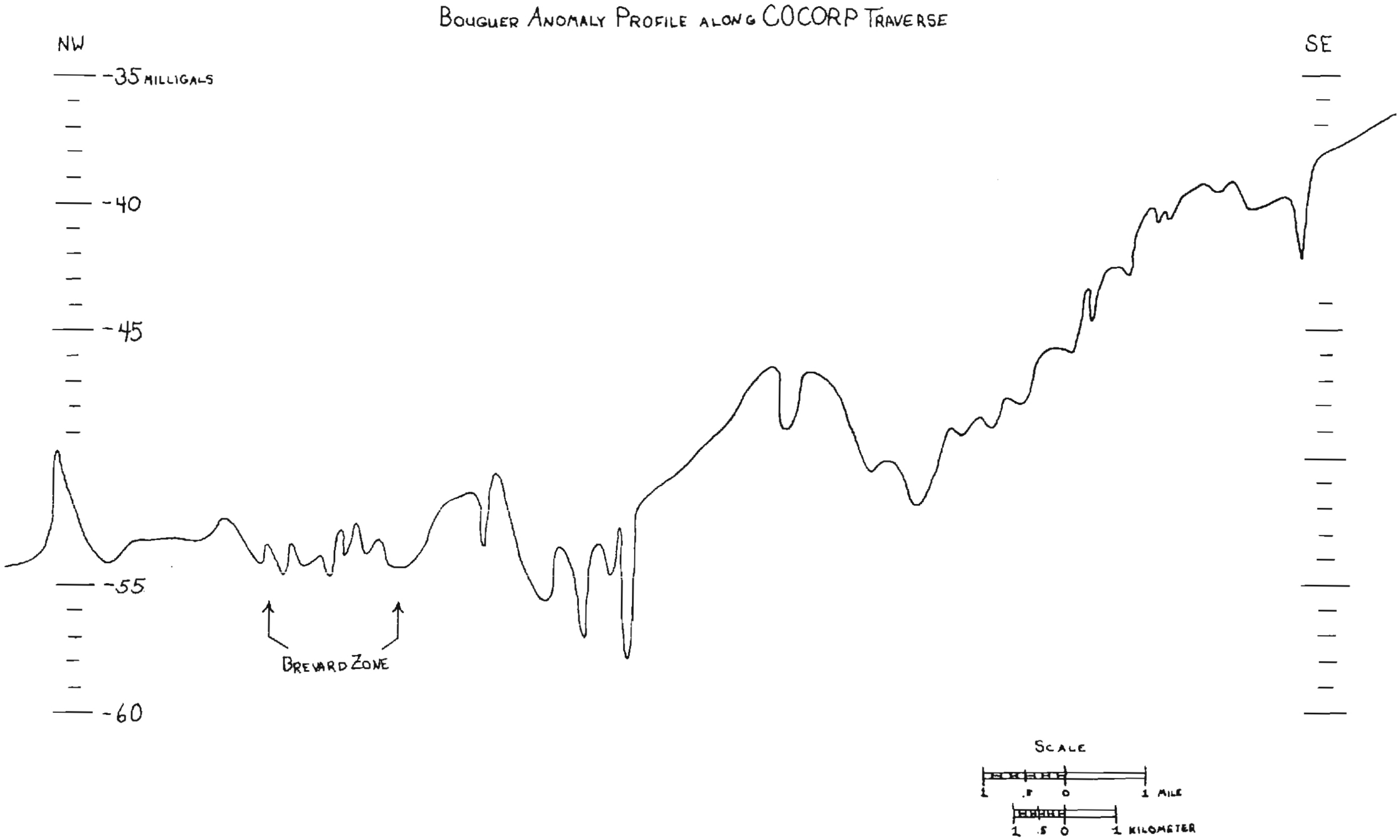

Figure 3. Preliminary profile of simple Bouguer gravity along line A B of Figure 2.

Denman's readings are available at the School of Geophysical Sciences, Georgia Tech. Figure 4 shows area B (and area A) on the Bouguer Map of Georgia; the intense high in area B is due to mafic and amphibolite bodies of the Charlotte Belt (Obaoye, 1979), while the low to the south is due to the Danburg granite and associated bodies. Figure 5 is a more detailed map of the study area, with the major belts of the Piedmont and the granitic plutons indicated on it. We propose to take about 1500 gravity stations within this area, which is about 2000 sq. km. The acquired and interpretation of this data should take 18 months, based on our experience with work under this contract. Stations will be taken at 1/2 km spacing along the COCORP line 1, and at 1 km spacing over and around the Elberton and Danburg granites. Other areas will be filled in at 1 - 2 km spacing, depending on the sharpness of the anomalies. The Siloam granite will be examine if time and funds permit. As before, elevations will be taken from Topo sheets.

The philosophy for determining which structures should be studied is based on structural control available from the COCORP line, the testing of structural ideas that have arisen as a result of the COCORP data, and the presence of sufficient density contrasts in the target structures to enable a determination of subsurface structures. Accordingly, as before we will take closely spaced stations along the COCORP line 1 and we will examine structures near it. As discussed before, probably the most interesting structures to examine gravimatically are two granitic plutons in the area, the Elberton granite and the Danburg granite. Since the granites in the Piedmont are generally of lesser density than the surrounding rocks, subsurface

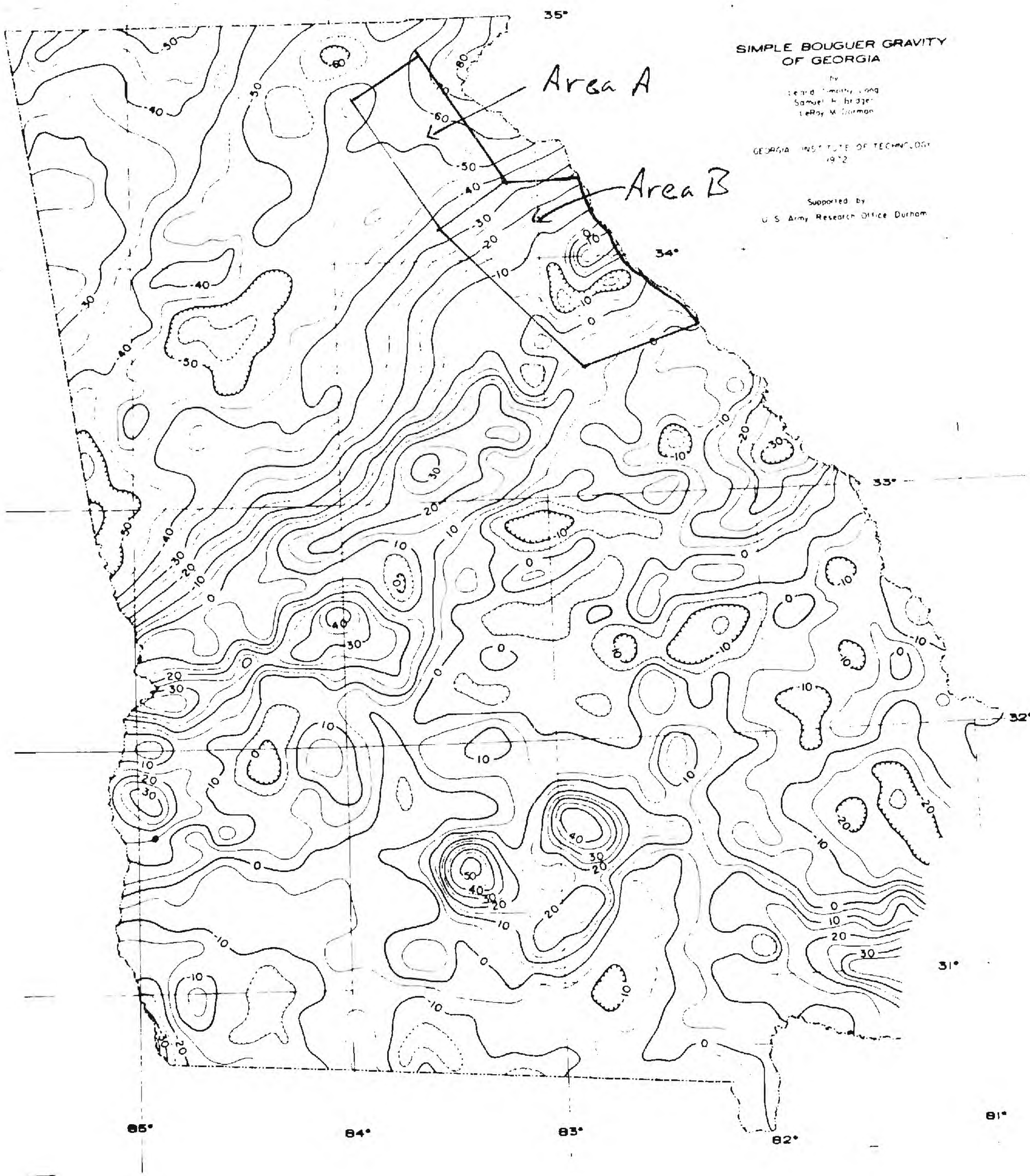

Figure 4. Simple Bouguer gravity map of Georgia, from Long (1974). The area surveyed under the present contract (area A) and the area of the proposed survey (area B).

structure can be obtained. Further, the structural relations, and particularly the depth extent, of these plutons should provide a good test of the ideans advanced in Cook et al. (1979a, b); specifically, the plutons should not pass through Cook et al's. proposed sole thrust, which is interpreted by Cook et al. to lie between 3.5 to 4.5 sec. two way travel time in this region.

Previous work on the Elberton and Danburg granites indicates their usefulness in studies of late deformation in the Southern Appalachians. The Elberton granite is relatively old (350 m.y.) and shows little evidence of post-emplacement movement, deformation or metamorphism based on paleomagnetic, geochemical and field evidence (Whitney et al., 1980). The COCORP line 1 passes over the Elberton granite between stations 1350 and 1450; the record section indicates definate reflectors on either side of the granite, but returns are much weaker or non-existant within the granite. It should be noted that Fig. 5 shows the boundaries of the Elberton granite as they are shown on the Geological Map of Georgia issued by the Georgia Geological Survey in 1976. Field mapping at the University of Georgia has indicated that the actual exposure of Elberton granite differs substantially from that shown in Fig. 5. We will maintain a close liason with the University of Georgia and have been promised access to their mapping results for the purpose of correlation with the gravity field. Gravimetically, the Elberton granite lies at the southeast edge of the Piedmont gravity gradient, which is enhanced in this area by strong positive Bouguer anomalies associated with mafic and ultramafic metamorphic rocks of the Charlotte Belt (Obaoye, 1979). Careful attention will have to be paid to the problem of removing the

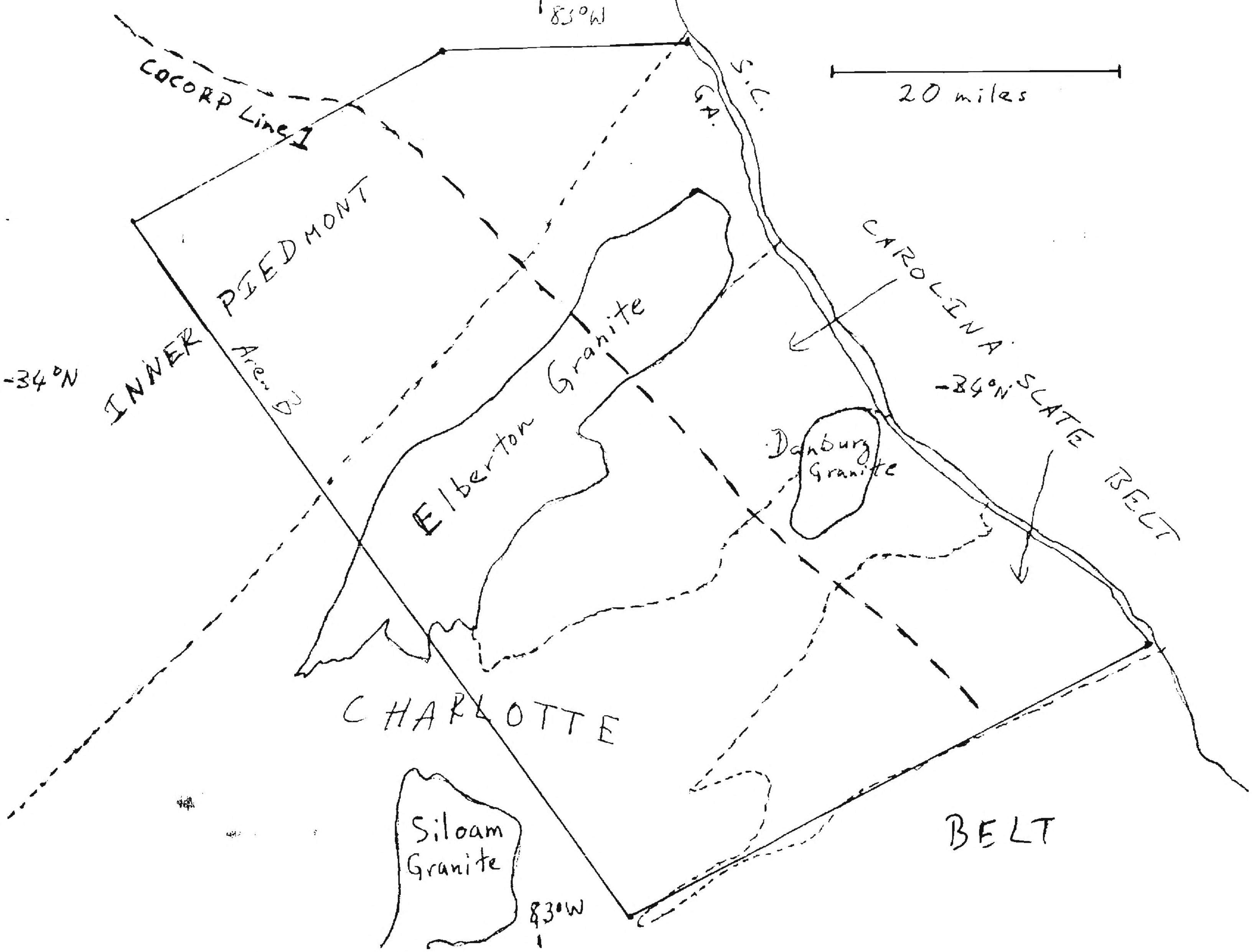

Figure 5. Simplified geological map of the proposed study area (area B). Geology based on Geological Map of Georgia, published in 1976 by the Geological Survey of Georgia, Atlanta, Georgia.

"regional" field to isolate the gravity signature of the Elberton granite: we will attempt to accomplish this by modelling of the deep structure and the mafic bodies causing the regional field (see Long, 1979; Obaoye, 1979).

In spite of these difficulties, the structural importance and the work done in other fields (paleomagnetism, geochemistry, isotopic age dating and analysis, field mapping; Whitney et al., 1980) make the Elberton granite an important target. To assist in the interpretation of the data, density determinations on samples of the Elberton granite and the surrounding country rocks will be made. We anticipate that three-dimensional gravity interpretations will be necessary; we propose to use the method of Talwani and Ewing (1960). In addition, to correct for the regional field it will be necessary to model the positive anomalies for mafic and ultramafic metamorphic rocks of the Charlotte Belt immediately southeast of the Elberton granite (these anomalies are the local high seen in Area B in Figure 4). Modelling of these bodies may also yield useful results in elucidating structural relations of Cook et al's. proposed thrust - Long (1979) indicates a considerable depth extent (up to 20 km deep) for some of the bodies, whereas Obaoye (1979) finds a maximum depth extent of 10 km. Detailed modelling, guided by density samples, should determine the true depth extent. As with the pluton, these bodies should not pass through the sole plane of the proposed thrusting.

The Danburg granite, by contrast, represents a relatively easy target for gravimetric study. It is known to have a pronounced gravity signature (the low in Area B or Figure 4; see also Long et al., 1976), and lies well southeast of the Piedmont gravity gradient. A preliminary interpretation of the gravity field of this body has been made by Long et al. (1976), indicating a depth extent of about 10 km; however Long et al's. survey did not cover the Danburg granite completely, only two dimensional interpretation methods were used, and because of the partial coverage it is not clear that the profile chosen runs across the center of the body. We propose making a full survey and interpreting the results with three dimensional models. The Danburg granite is believed to be about the same age as the Siloam granite to the southwest, that is about 265 m.y. old. This would make it one of the youngest, plutons in the crystalline Piedmont of the Southern Appalachian.

Instruments and Facilities.

A Lacoste-Romberg gravimeter, owned by the University of Georgia, is available for our use. The School of Geophysical Sciences, Georgia Tech, owns several vehicles and a boat suitable for access to the survey area. Computing for this project will be carried out on a CDC CYBER 74 at the Rich Electronic Computing Center at Georgia Tech. Calcomp and electrostatic plotters are available. A reduction program for gravity data, including tidal corrections, is available at two on-line terminals at the School of Geophysical Sciences. Modelling programs for two and three dimentsional bodies are available at the School of Geophysical Sciences.

Personnel.

Dr. Anton M. Dainty, Associate Professor of Geophysics and Dr. Leland T. Long, Associate Professor of Geophysics, both of the School of Geophysical Sciences at Georgia Institute of Technology, will serve as Principal Investigators. Dr. Dainty will spend 15% time on this project and Dr. Long 5% time.

Dr. Dainty has experience interpreting gravity data in conjunction with seismic results in the Maritime Appalachians of Canada, as well as previous work under this grant. Dr. Long has considerable experience in the collection and interpretation of gravity and seismic data in the Southern Appalachians. We will maintain a close liason with the University of Georgia, which has an ongoing program of geological field mapping, geochemistry, isotopic age dating and paleomagnetic investigations in this area. A graduate research assistant will be employed, together with undergraduate assistants for field crews and routine reduction of the data.

Bouguer gravity in northeastern Georgia: A buried suture, a surface suture, and granites

ANTON M. DAINTY
JAMES E. FRAZIER* } *School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia 30332*

ABSTRACT

A Bouguer gravity map of an area of northeastern Georgia encompassing parts of the Inner Piedmont, Charlotte belt, and Carolina Slate belt has been constructed from gravity stations spaced ~2 km apart. Anomalies in the Charlotte–Carolina Slate belts are due to metamorphosed mafic rocks in the upper crust (depth extent <5 km, positive anomalies) and unmetamorphosed Alleghenian granites that extend to depths of as much as 16 km and produce negative anomalies. One of these granites is the Danburg granite; the other granite is not exposed at the surface. The Elberton granite in the Inner Piedmont has too little gravity expression in this survey for a structural interpretation, because the density contrast between the Elberton and the country rock is too small. The Middleton-Lowndesville fault zone is the geologically mapped boundary between the Inner Piedmont and the Charlotte–Carolina Slate belts in this area; there is a sharp gradient of Bouguer gravity across the fault zone caused by the juxtaposition of the shallow mafic rocks of the Charlotte–Carolina Slate belts with Inner Piedmont rocks. There is also a dramatic difference in the nature of the gravity field across the fault zone due to the presence of near-surface sources on the southeast (Charlotte–Carolina Slate belts) side and the absence of such sources on the northwest (Piedmont) side. We interpret the Middleton-Lowndesville fault zone as a surface (that is, exposed) suture between two suspect terranes accreted onto the North American margin during the Paleozoic. The northwest part of the map is occupied by a broad gradient that is part of the Piedmont gravity gradient, a feature that runs along the entire southern Appalachians, crosscutting mapped boundaries between belts. We interpret this gradient as representing the continental margin of early Paleozoic North America and as being caused by the juxtaposition of sialic Grenville mid- to lower-crustal material with more mafic material to the southeast. This buried suture is covered by overthrust terranes. We propose that thrusting must extend at least to a point southeastward of the suture.

INTRODUCTION

Much recent work on the tectonics of the southern Appalachians has focused on the origin of the various belts of the southern Appalachians and their tectonic relations to each other (Hatcher, 1972; Cook and others, 1979, 1981; Long, 1979; Ellwood, 1982; Whitney and others, 1978; Williams and Hatcher, 1982; Sinha and Zietz, 1982). Several issues have been identified as important to an understanding of the southern Appalachians as a result of these works. One is the possibility that many of the belts are allochthonous either because of thrusting to the northwest (Hatcher, 1972; Cook and others, 1979, 1981) or because of the addition of microplates ("suspect terranes," "allochthonous terranes") to the margin of ancient North America during the Paleozoic (Williams and Hatcher, 1982; Whitney and others, 1978). Most of the authors cited believed that both processes occurred to a greater or lesser degree. An important topic developing from the allochthonous hypothesis is the subsurface location of the edge of "original" (that is, Grenvillian) North American crust before thrusting and/or the accretion of microplates.

The timing of various episodes of thrusting and/or accretion, metamorphism, and igneous activity has received renewed attention in the light of these new concepts of Appalachian tectonics. Of particular interest in this paper are the Alleghenian ("Hercynian") granitic plutons of the Piedmont (Fullager and Butler, 1979; Sinha and Zietz, 1982). These plutons postdate the metamorphism of the Piedmont at ~400 m.y. B.P. (Fullager, 1971) and presumably are associated with the final stage of the tectonic development of the Appalachian orogen.

This paper presents structural interpretations of the Bouguer gravity field of an area of northeastern Georgia (Figs. 1, 2, 3) (Frazier, 1982). These interpretations deal with the addition of microplates to the North American continent, specifically the Charlotte–Carolina Slate belts microplate (Williams and Hatcher, 1982), the location of the edge of Grenville crust of early Paleozoic North America, and the nature of Alleghenian plutonism.

GEOLOGIC BACKGROUND

Figures 1 and 2 show the position of the study area. Figure 1 is a generalized geological map of the study area, which lies on the boundary of the Inner Piedmont and the Charlotte–Carolina Slate belts (King, 1959; Williams and Hatcher, 1982; Whitney and others, 1980a). In this work, we shall treat the Charlotte belt and the Carolina Slate belt as a single unit, following Williams and Hatcher (1982), because this interpretation is supported by the gravity data. The boundary between the Inner Piedmont and the Charlotte–Carolina Slate belts is the Middleton-Lowndesville fault zone, a steeply dipping zone of cataclasis with both early, ductile movement and later, brittle movement (Rozen, 1973). The fault zone is a tight isoclinal syncline along which thrust or reverse faulting, or both, has occurred (Rozen, 1973), and it may be regarded as the extension of the Kings Mountain belt into the study area (Whitney and others, 1980a; Fig. 1). The Middleton-Lowndesville fault zone may also be an extension or splay of the Towaliga fault, which has been taken as the boundary between the Charlotte–Carolina Slate belts and the Inner Piedmont

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Geological Society of America Bulletin, v. 95, p. 1168–1175, 8 figs., October 1984.

grt	garnet
kfs	potassium feldspar
mi	white mica
ms	muscovite
ms(F)	fluormuscovite
pg	paragonite
ph	phlogopite
pl	plagioclase
qz	quartz
sil	sillimanite
sid	siderophyllite
st	staurolite

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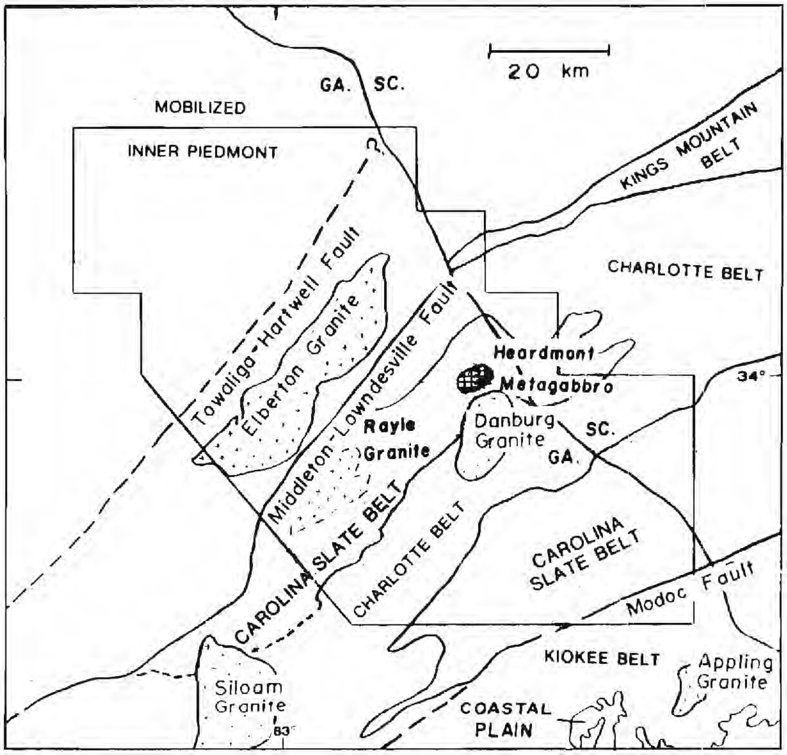

Figure 1. Geologic map of gravity survey area (enclosed by solid line) and surrounding region in northeast Georgia and adjacent South Carolina, modified from Whitney and others (1980a) and Georgia Geological Survey (1976). The position of the buried "Rayle granite" proposed in this paper is shown; this body is not exposed at the surface.

(Hatcher, 1972). The Towaliga fault is shown as passing through the northwest part of the study area on the Geological Map of Georgia (Georgia Geological Survey, 1976; Fig. 1), but if this fault has been correctly mapped, it cannot be the boundary between the Inner Piedmont and the Charlotte–Carolina Slate belts in this area, because Inner Piedmont rocks are found to the southeast of it (Whitney and others, 1980a). Williams and Hatcher (1982) suggested that the boundary between the Inner Piedmont and the Charlotte–Carolina Slate belts is a suture between microplates.

Exposed rocks in the study area may be divided into the typical country rocks of the Inner Piedmont, Charlotte belt, and Carolina Slate belt, respectively, and two Alleghenian granitic plutons, the Elberton and Danburg granites. (The Siloam and Appling granites shown in Fig. 1 are also of Alleghenian age.) The country rocks of the crystalline belts have been metamorphosed, presumably by burial, with the peak of metamorphism at about 400 m.y. B.P. (Fullager, 1971) and have since been exhumed by uplift and erosion (Dallmeyer, 1978). The Alleghenian granitic plutons have not been metamorphosed.

Country rocks of the Inner Piedmont are predominantly schists and gneisses of high grade; sillimanite-grade rocks and migmatites are present in places. These rocks have been uplifted at least 12 to 15 km, on the basis of estimates of the original depth of emplacement of the Elberton granite (Stormer and others, 1980) and the Stone Mountain granite, an Alleghenian pluton to the northwest of the study area (Whitney and others, 1976). Dallmeyer (1978) suggested a greater uplift of ~25 km for the central Inner Piedmont. To the southeast of the Middleton-Lowndesville fault zone, rocks of the Charlotte belt are of plutonic aspect, both felsic, such as granites and granite gneisses, and mafic, such as metagabbros. The Carolina Slate belt in this region consists of predominantly volcanic rocks, both felsic and mafic, and volcanic derived sediments of early Paleozoic age (Paris, 1976; Maher and others, 1981). Metamorphic grade of the Charlotte belt is upper amphibolite and is lower than that of the adjacent Inner Piedmont (Whitney and others, 1980a). The Carolina Slate belt shows only low-grade metamorphism. The relationship of the Carolina Slate belt and the Charlotte belt has been the subject of controversy. Hatcher (1972) interpreted the Carolina Slate belt rocks as lying in normal stratigraphic succession on top of Charlotte belt rocks in synclinoria. Whitney and others (1978), however, interpreted the Carolina Slate belt as an island arc formed on oceanic crust. In their interpretation, the relationship between the Charlotte and Carolina Slate belts is not specified.

The fourth rock type in the study area is Alleghenian granite, represented by the Elberton granite and the Danburg granite. Both bodies are postmetamorphic, that is, younger than ~400 m.y., as shown by a lack of metamorphic fabric and deformation (Stormer and others, 1980; Fullager and Butler, 1979). The Elberton granite has been dated as being between 350 m.y. old (Rb-Sr, Whitney and others, 1980b) and 320 m.y. old (U-Pb, Ross and Bickford, 1980); the Danburg granite has not been dated but is geochemically very similar to the Siloam granite (Fullager and Butler, 1979; Fig. 1), which has been dated at 265 m.y. B.P. (Rb-Sr, Jones and Walker, 1973). Sinha and Zietz (1982) consider both bodies to be part of a "Hercynian magmatic arc," represented by many similar bodies in the southeastern United States. Detailed study of the two bodies, however, reveals many differences. Besides the suspected difference in age, the bodies show different textures. The Elberton granite is fine grained, and the Danburg is porphyritic. More importantly, different origins have been proposed for the granites. Stormer and others (1980) presented a model of the formation of the Elberton granite by anatexis of mafic to intermediate igneous rocks at 18- to 20-km depth, followed by emplacement at 13- to 15-km depth. Fullager and Butler (1979) considered the Siloam (and by analogy, the Danburg) granite as originating from a magma, the source of which was in the upper mantle, or possibly lower crust, on the basis of a low Sr^{87}/Sr^{86} ratio of 0.705. It must be noted, however, that the Sr^{87}/Sr^{86} ratio of the Elberton granite is 0.704.

A final question that must be considered is the structural style of the area. Most writers agree that thrusting to the northwest with overturned

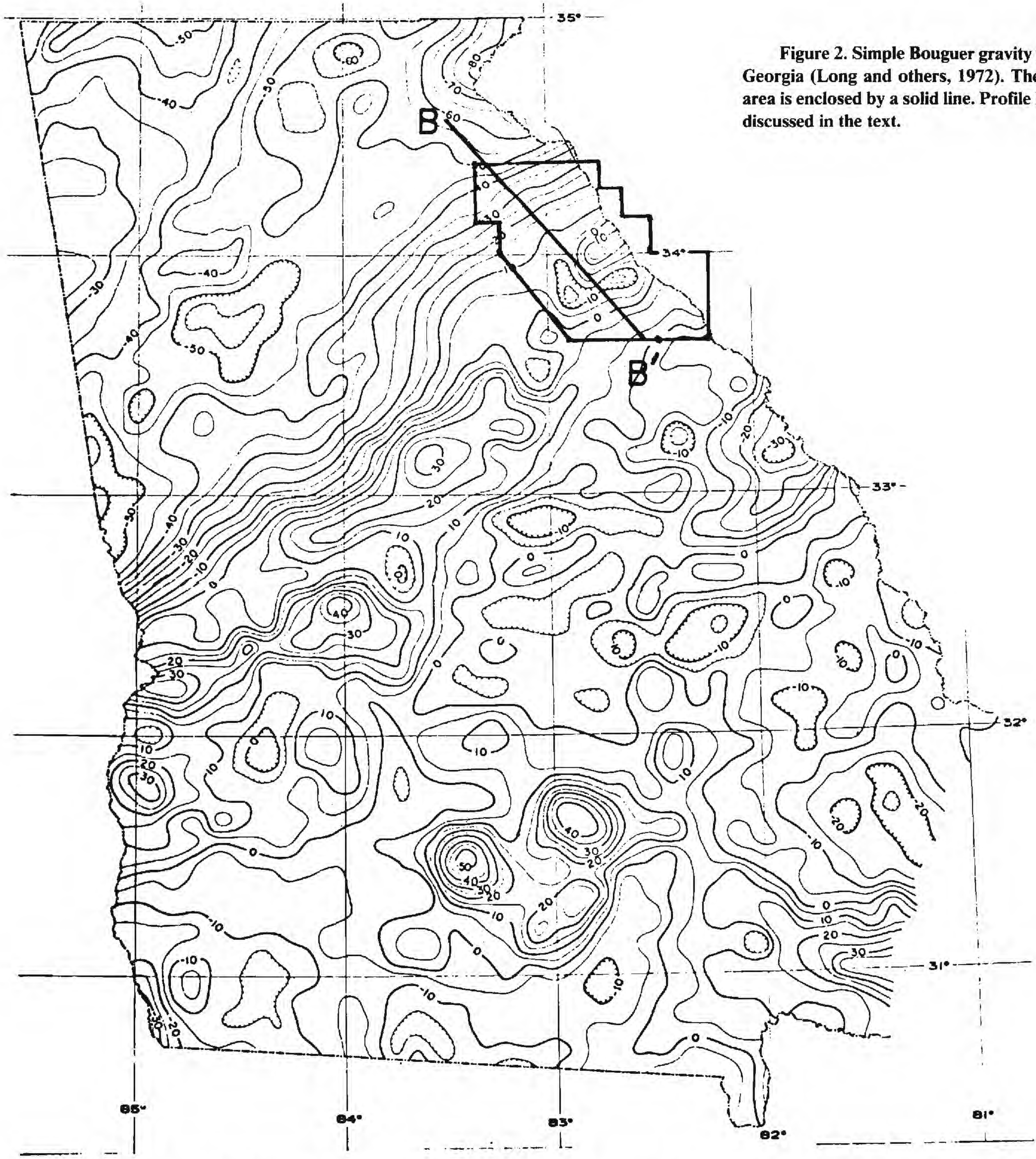

Figure 2. Simple Bouguer gravity map of Georgia (Long and others, 1972). The study area is enclosed by a solid line. Profile B–B′ is discussed in the text.

folds and nappes is present in the Inner Piedmont. Hatcher (1972) proposed that the Kings Mountain belt (or the Middleton-Lowndesville fault zone in the study area) was the southeastern limit of thrusting, and that the folds and faults of the Charlotte and Carolina Slate belts were more upright. In later work, Williams and Hatcher (1982) suggested that the Charlotte–Carolina Slate belts, considered as a single unit, were an Avalonian terrane that had been sutured onto the North American continent in the Paleozoic. The Inner Piedmont (and the Blue Ridge to the northwest) are suspect terranes that have been thrust over the Grenville-age rocks of the late Precambrian–early Paleozoic continental margin, at least in part during the Alleghenian orogeny. Cook and others (1979, 1981), on the basis of COCORP reflection studies in the area, interpreted a master sole thrust extending from the Valley and Ridge to the Coastal Plain, passing through the study area at ~15-km depth. Movement on this sole thrust

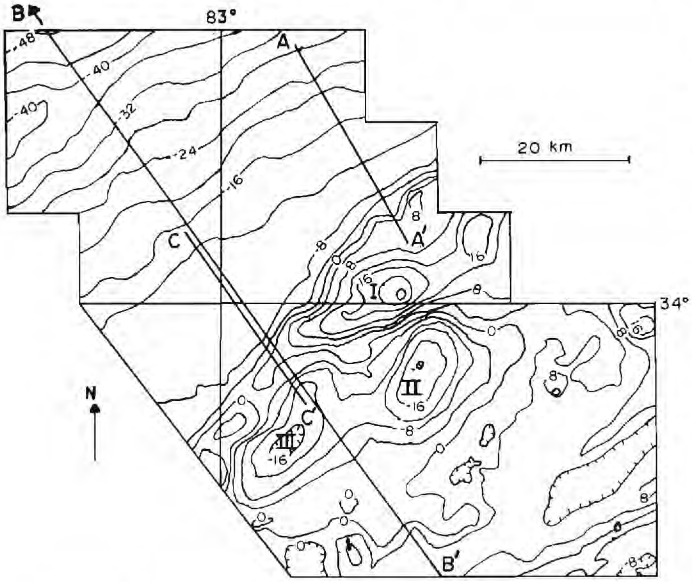

Figure. 3. Simple Bouguer gravity map of the study area, after Frazier (1982). Anomalies I, II, and III, and profiles A–A′, B–B′, and C–C′ are discussed in the text. Contour interval is 4 mgal.

must have been at least 260 km to the northwest, occurring throughout the Paleozoic and ending at the close of the Alleghenian orogeny. In this interpretation, all surface rocks in the study area are allochthonous.

PREVIOUS GEOPHYSICAL WORK

The first regional gravity studies in this area were the works of Long and others (1972, 1976a), conducted at a spacing of ~7 km (Fig. 2). Major features in Figure 2 were discussed by Long (1974, 1979). Short-wavelength Bouguer anomalies in the Piedmont were found to be strongly correlated with surface rocks, positive anomalies with mafic rocks, and negative anomalies with felsic rocks. Also present in Figure 2 is a large gravity gradient between negative Bouguer anomalies in the northwest portion of the map and near-zero average Bouguer anomalies in the southeast portion. This gradient, which passes through the study area, is known as the Piedmont gravity gradient. It was interpreted in North Carolina as an expression of the Charlotte belt–Carolina Slate belt contact by Best and others (1973), whereas Long (1979), Obaoye (1979), and Cook and Oliver (1981) interpreted it as a result of the combined effects of crustal thickening to the northwest, near-surface mafic bodies to the southeast in the Charlotte–Carolina Slate belts, and additional density variations at mid-crustal depths. Long (1979) and Cook and Oliver (1981) considered the point of crustal thickening as expressed in the Piedmont gravity gradient to be a rifted margin of ancient North America formed in the late Precambrian–early Paleozoic.

Obaoye (1979) conducted a more detailed (average spacing 1 to 2 km) gravity survey in the area immediately northwest of the present area of study; some of Obaoye's data have been incorporated in the present study. Besides studying the Piedmont gravity gradient, Obaoye investigated the gravity anomalies over the Brevard zone. He found only a small local anomaly associated with the surface trace of the fault, probably due to greater weathering of Brevard zone rocks. This suggests that the Brevard zone is not a major crustal boundary or suture. Denman (1974) and Long and others (1976b) studied the Bouguer gravity field of the southeastern portion of the study area near Clark Hill reservoir; these data have been incorporated in the present study. A strong correlation between surface rocks of the Charlotte and Carolina Slate belts and Bouguer gravity was found, with positive Bouguer anomalies associated with mafic rocks and a pronounced negative Bouguer anomaly associated with the Danburg granite. These anomalies are discussed in the next section.

A great deal of aeromagnetic work is available in the study area. Zietz and others (1980a) made a compilation of aeromagnetic data for the entire Appalachian orogen, including the study area. An aeromagnetic map of Georgia also has been published (Zietz and others, 1980b). Both Popenoe and Zietz (1977) and Williams and Hatcher (1982) used regional aeromagnetic and gravity data to delineate crustal boundaries in the Piedmont.

Refraction seismology (Kean and Long, 1980) and synthetic seismogram analysis (Lee and Dainty, 1982) have been used to determine crustal structure. In an area that included the southeastern part of the study area, Lee and Dainty found a relatively thin (33-km-thick) crust, with a major crustal layer of compressional wave velocity 6.0 km/sec between 6- and 29-km depth, indicating dominantly felsic rocks. This contrasts with the extensive mafic rocks exposed at the surface. A thin, higher-velocity (6.7 km/sec) layer, 4 km thick, is present at the base of the crust. Kean and Long (1980) found similar results in the Charlotte and Carolina Slate belts, but they also examined a much wider area of the southeastern United States. They presented evidence for substantial thickening of the crust (40–50 km thick) in northwestern Georgia.

Cook and others (1979, 1981) presented data from a COCORP survey across strike from the Valley and Ridge of Tennessee through Georgia close to the South Carolina border, ending at Savannah. This survey passed through the study area approximately along line B–B′ (Figs. 2, 3). Cook and others (1979) noted a strong reflector that could be traced from Tennessee to a point in the Inner Piedmont northwest of the Elberton granite. They interpreted the reflector as indicating the presence of Valley and Ridge sediment beneath the Blue Ridge and the Inner Piedmont, which must have been overthrust to the northwest. From the Inner Piedmont southeastward, they found the upper 10 to 15 km of the crust to be relatively transparent to seismic energy, with reflections appearing below this. The prominent reflector seen under the Blue Ridge, however, either is not present or exhibits a different character. Cook and others (1979, 1981) postulated that the seismically transparent upper part of the crust is a sheet of crystalline rocks thrust at least 260 km to the northwest over sediments or metasediments along a master sole thrust lying at depths of 5 km in the Blue Ridge to 15 km in the study area and southeastward. Cook and others (1981) and Iverson and Smithson (1982), however, presented other interpretations of the COCORP data that agree with Hatcher's (1972) model in which thrusting ends at the Kings Mountain belt. Both Cook and others (1981) and Iverson and Smithson (1982) identified the termination in the Inner Piedmont of the strong reflector noted under the Blue Ridge as the edge of the early Paleozoic North American continental shelf.

MODELING OF THE BOUGUER GRAVITY FIELD

Figure 3 is a map of simple Bouguer gravity in the study area (Frazier, 1982). A total of 3,467 gravity stations was used in constructing this map, about 1,700 from previous investigations (Denman, 1974; Long and others, 1976b; Obaoye, 1979). Elevations and locations for the gravity stations were estimated from 1:24,000 topographic sheets. The resulting values of simple Bouguer gravity are estimated to be accurate to ±0.15 mgal, with the main source of error being the uncertainty in elevation. A density of 2.67 g/cc was used for the Bouguer reduction.

Five features and one nonfeature of the area shown in Figure 3 have been selected for investigation. The Piedmont gravity gradient occupies the northwest part of the map, with a much steeper, more localized gradient coincident with the mapped trace of the Middleton-Lowndesville fault zone, running from northeast to southwest across the center of Figure 3. Profile lines A–A′ (Fig. 3), B–B′ (Figs. 2, 3), and C–C′ (Fig. 3) were chosen to investigate the gradients; line B–B′ used data from Obaoye (1979) as well as from the present study. To model these profiles, two-dimensional modeling techniques (Talwani and others, 1959) were used.

On the southeast side of the Middleton-Lowndesville fault zone, there are several prominent anomalies, notably anomalies I, II, and III (Fig. 3). Anomaly I lies over the Danburg granite and reaches a minimum value of −20 mgal, and anomaly II lies over a metamorphosed gabbroic intrusive of the Carolina Slate belt and reaches a maximum value of 24 mgal. This intrusive will be referred to as the Heardmont metagabbro in this paper. As these anomalies are associated with surface exposures of rocks that are reasonable candidates for causative bodies, we have assumed that the gravity anomalies are due to the continuation of these rocks downward. Anomaly III, however, which lies within the Carolina Slate belt, is not associated with any surficial exposures of likely candidates for causative rocks. Owing to its similarity to anomaly I, associated with the Danburg granite, we have assumed that anomaly III, which reaches a minimum value of −17 mgal, is due to a buried granite pluton ("Rayle granite") similar to the Danburg granite. Granite boulders similar to the Danburg granite have been found in the area of anomaly III (B. B. Ellwood, personal commun.). Bodies corresponding to these anomalies have been modeled in three dimensions using the method of Garland (1965); a flat regional field of 0 mgal Bouguer has been assumed.

There is a marked contrast in the nature of the gravity field on the northwest side of the Middleton-Lowndesville fault zone compared to the southeast side. The prominent local anomalies that are a feature of the gravity field to the southeast are absent to the northwest. Specifically, there is little if any gravity signature associated with the Elberton granite, which lies immediately northwest of the Middleton-Lowndesville fault zone. Either this body is very thin, or it does not have a significant density contrast with the surrounding country rock.

On account of their proximity, causative bodies for anomalies I and II (the Danburg granite and the Heardmont metagabbro, respectively) were modeled together and are presented in Figure 4. The Danburg granite appears as a stocklike body, extending to 16-km depth if the density contrast between the granite and the surrounding country rock is −0.1 g/cc. The Heardmont metagabbro, for which a density contrast of 0.2 g/cc has been assumed, appears as a linear intrusion just to the southeast of the Middleton-Lowndesville fault zone. The configuration of this body may be controlled by the fault zone. The model shown in Figure 4 explains the observed gravity field within ~1 mgal.

Ideally, to determine density contrasts, fresh samples should be taken from the causative bodies and the country rocks. In the southeastern United States, this is not generally possible because of the deep weathering characteristics of the region, unless the rock is quarried. B. B. Ellwood of the University of Georgia kindly made available samples from the Danburg and Elberton granites, but fresh samples from other rocks in the area could not be obtained. From 6 samples of the Danburg granite, the density was determined to be 2.7 ± 0.1 g/cc (2 standard deviations), whereas the density of the Elberton granite is 2.66 ± 0.06 g/cc, based on analysis of 8 samples. Using the density contrast of −0.1 g/cc for the Danburg granite cited above, we would conclude that the density of the country rocks of the Charlotte–Carolina Slate belts is 2.8 g/cc, and the density of the Heardmont metagabbro is 3.0 g/cc. These are reasonable numbers for the rock types involved. For the Elberton granite, which has a density similar to that of the Danburg, the lack of an observed gravity anomaly indicates that the country rocks of the Inner Piedmont have a density of ~2.7 g/cc and are somewhat less dense than the rocks of the Charlotte–Carolina Slate belts. The possibility that the Elberton granite is too thin to produce

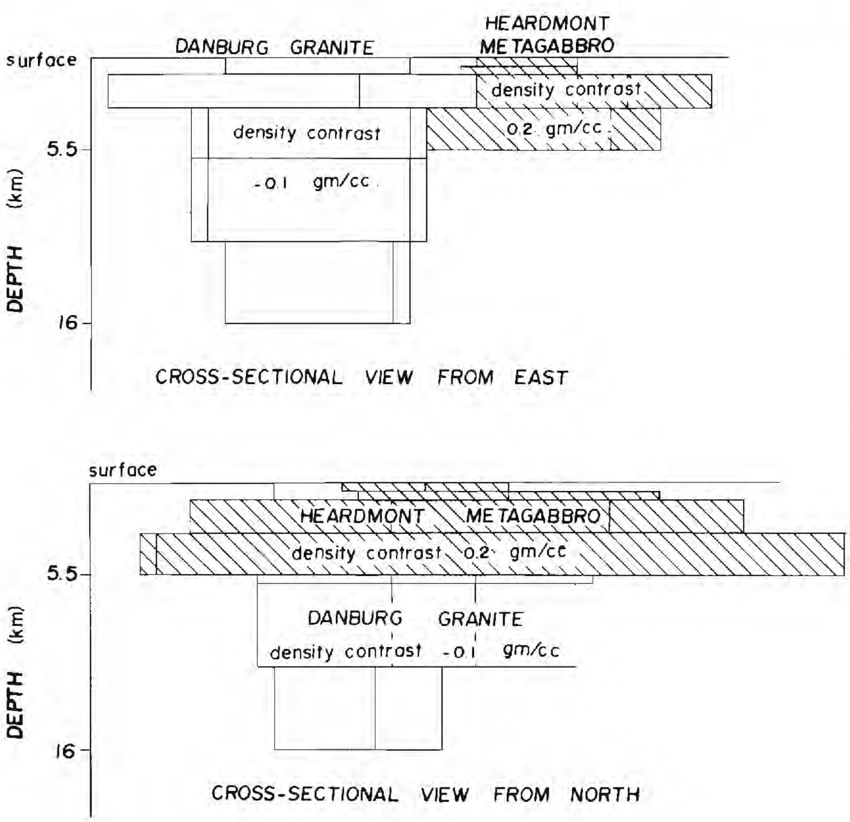

Figure 4. Top: cross-sectional diagram depicting the results of three-dimensional modeling of the Danburg granite and the Heardmont metagabbro viewed from the east. Lined pattern denotes the Heardmont metagabbro. No vertical exaggeration. Bottom: view from the north.

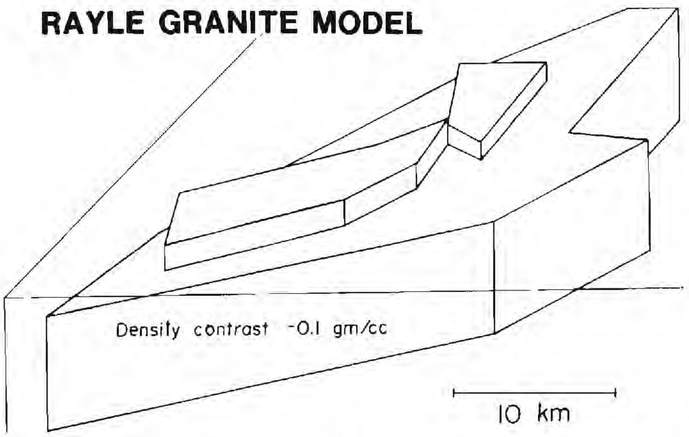

Figure 5. Three-dimensional projection of a model of the proposed "Rayle granite." View is from the south. No vertical exaggeration.

an anomaly depends on the density contrast chosen; for a density contrast of –0.1 g/cc, the Elberton granite would produce a recognizable gravity signature if it were substantially thicker than ~100 m. Considering the large areal extent of and extensive quarrying in the Elberton, it seems reasonably certain that the granite is at least 1 km thick, limiting its density contrast to about –0.01 g/cc.

It must be realized that gravity models are nonunique, and that many different models could be proposed to explain a given gravity anomaly. To partially investigate this problem, we attempted to model the Danburg granite using density contrasts of –0.05 and –0.15 g/cc. For a density contrast of –0.05 g/cc, no model that fit the gravity field could be found, because the size of body necessary to produce the total amplitude of the anomaly spread the anomaly too broadly. At –0.15 g/cc, the Danburg granite extended to a depth of 6 km but was still a stocklike body.

Figure 5 shows a 3-dimensional projection of a similar model for anomaly III, the "Rayle granite," using a density contrast of –0.1 g/cc. The model suggests a stocklike body similar to the Danburg granite but not yet unroofed. The maximum depth of the body is 8 km in this model.

To investigate the Piedmont gravity gradient and the Middleton-Lowndesville fault zone, two-dimensional modeling along three profiles, A–A′ (Fig. 6), B–B′ (Fig. 7), and C–C′ (Fig. 8), are presented. Profile A–A′ shows a fit to both the Piedmont gravity gradient and the Middleton-Lowndesville fault anomaly in the northeastern part of the study area and does not cross the Elberton granite. The Middleton-Lowndesville fault zone anomaly is modeled as being due to near-surface mafics on the southeast (Charlotte–Carolina Slate belts) side of the fault. Note that these bodies do not extend to depths in excess of 5 km. The Piedmont gravity gradient is modeled by a slab centered at 18-km depth, starting in the Inner Piedmont ~10 km northwest of point A and running to the northwest. A density contrast of –0.15 g/cc has been assumed and leads to a total thickness of 16 km for the slab, if the observed anomaly values seen in Figure 2 northwest of the study area are to be produced by the model. The thickness of the slab and its density contrast are indeterminate in the sense that any combination of density contrast and thickness such that their product is -2.4×10^5 g/cm^2 will produce a similar fit. Of more relevance is the depth to the center of the slab, 18 km. A body at substantially deeper depths than this, such as one centered at 35 km representing crustal thickening, cannot by itself simultaneously satisfy the total change in Bouguer gravity values across the Piedmont gravity gradient and the steepness of the gradient.

A difficulty with profile A–A′ is the lack of coverage of the Piedmont gravity gradient to the northwest of the study area. Accordingly, data for the present study were combined with data from Obaoye (1979) to form profile B–B′ (Figs. 2, 7). Only a single body has been used to model the Piedmont gravity gradient, centered at a depth of 23.5 km and with a thickness of 11 km if a density contrast of –0.15 g/cc is used. Again, any slab centered at 23.5 km for which the product of density contrast and thickness yields -1.65×10^5 g/cm^2 will yield similar results. Slabs at significantly deeper depths cannot simultaneously satisfy the total Bouguer gravity change across the Piedmont gravity gradient and its steepness. Note that the southeasternmost extension of the buried slab is in the Inner Piedmont.

Detailed modeling of the gravity field associated with the Middleton-Lowndesville fault zone is shown on profile C–C′ (Figs. 3, 8). On both profiles C–C′ and A–A′, the anomaly is due to the abrupt contact along the Middleton-Lowndesville fault zone between the rocks of the Inner Piedmont and the more mafic surface rocks of the Charlotte–Carolina Slate belts to the southeast. Again, note that the mafic rocks do not extend to depths greater than 5 km, confirming the seismic results of Kean and Long (1980) and Lee and Dainty (1982). A small body with a density contrast of –0.01 g/cc has been added to the model for this profile to represent the effect of the Elberton granite. The maximum effect of this body is –0.3 mgal and is very marginal in terms of improving the fit to the

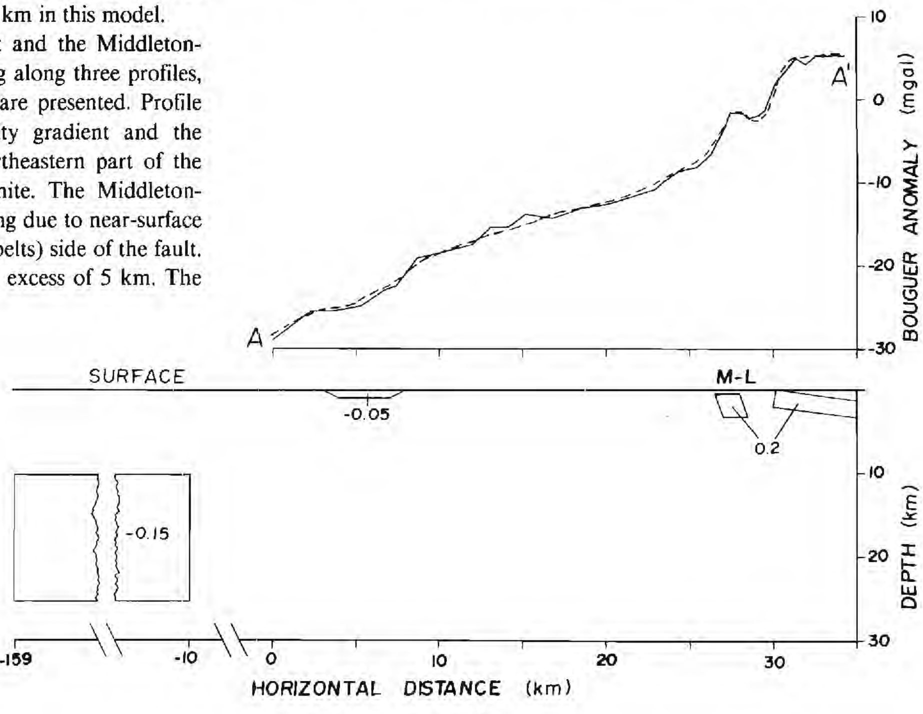

Figure 6. Diagram showing comparison of observed Bouguer anomaly with theoretical calculations (top) along profile A–A′. Solid line is the observed anomaly, and dashed line is the theoretical anomaly. Bottom half of diagram shows the two-dimensional model used for the theoretical calculations. Numbers are density contrasts in g/cc. M-L is the Middleton-Lowndesville fault zone. From Frazier (1982).

data. This result confirms our previous comments on the lack of gravity expression of the Elberton granite.

DISCUSSION AND CONCLUSIONS

The most important result of this study is the information on the nature of the Piedmont gravity gradient and that of sutures between belts (terranes) as exemplified by the Middleton-Lowndesville fault zone. These two phenomena are shown to be quite separate in this study. The Piedmont gravity gradient has been interpreted in this study as originating at mid- to lower-crustal depths, and not as the result of crustal thickening to the northwest, as envisaged by Long (1979), Obaoye (1979), and Cook and Oliver (1981). Both Long and Cook and Oliver, however, included lateral changes in crustal density in their models. We find that bodies at mid- to lower-crustal depths will produce the required combination of the total change of Bouguer gravity values across the gradient and the steepness of the gradient. To produce the observed steepness of the gradient, models that invoke crustal thickening at depths of 35 km must add other bodies closer to the surface. Long (1979), Obaoye (1979), and Cook and Oliver (1981) placed a large mafic body of positive density contrast and considerable (10–20 km) depth extent in the Charlotte–Carolina Slate belts to help to steepen the gradient. Our detailed study in this region of both the Middleton-Lowndesville fault zone and the anomalies of the Charlotte-Carolina Slate belts do not indicate the presence of such bodies; the deepest bodies found are granites with a negative density contrast. Explanations of the Piedmont gravity gradient involving crustal thickening are even more difficult to sustain in the area examined by Best and others (1973), where the gradient is steeper. Whereas the seismic evidence of Kean and Long (1980) indicates clearly that the crust thickens to the northwest, the manner and position of the thickening are not determined. Our interpretation suggests that the Piedmont gravity gradient is not the locus of this thickening.

We interpret the Piedmont gravity gradient as the boundary between the buried sialic Grenville crust of early Paleozoic North America and more mafic crust of various accreted microplates to the southeast. This interpretation agrees with Cook and Oliver (1981), Cook and others (1981), and Iverson and Smithson (1982) in their placing of the continental-shelf edge of ancient North America on the basis of COCORP seismic-reflection studies and gravity, and it also agrees with Long's (1979) positioning of the early Paleozoic rifted margin in this area. In arriving at this interpretation, we have considered the results of Taylor and Toksöz (1982), who demonstrated that the Grenville terrane in the northern Appalachians has lower compressional-wave velocities in the middle to lower crust, presumably indicating more sialic material, than do the accreted terranes to the southeast. This contrast is the physical cause of the lower crustal body shown in Figures 6 and 7. Another important consideration in our interpretation is the need for a model that will apply to the whole of the southern Appalachians, because the Piedmont gravity gradient runs along the entire orogen (Haworth and others, 1980). We call this buried contact a buried suture.

The Middleton-Lowndesville fault zone is considered to be a surface suture. The difference in the gravity field on either side of this boundary is marked, with numerous positive and negative anomalies due to near-surface rocks on the Charlotte–Carolina Slate belts side and few, if any, anomalies due to near-surface rocks on the Inner Piedmont side. Clearly, the Middleton-Lowndesville fault zone is a major boundary, at least in the upper crust. We follow Williams and Hatcher (1982) in suggesting that the Inner Piedmont and the Charlotte–Carolina Slate belts are separate microplates accreted to the early Paleozoic North American margin, thus producing the observed difference in the gravity field. This boundary is also evident on the magnetic map of Zietz and others (1980b). Other possible explanations are: (1) greater uplift of the Inner Piedmont along

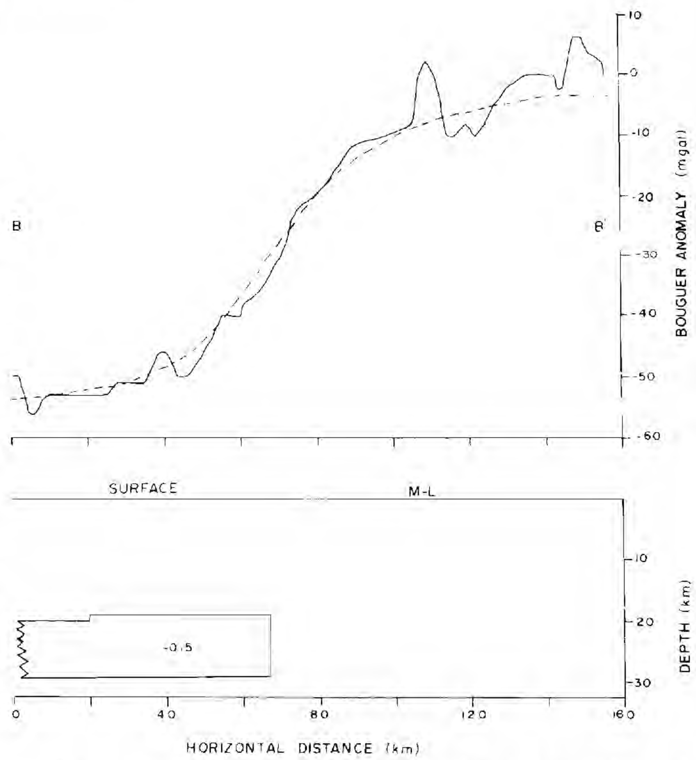

Figure 7. Comparison of observed and calculated anomalies and model for profile B–B′. Symbols as for Figure 6.

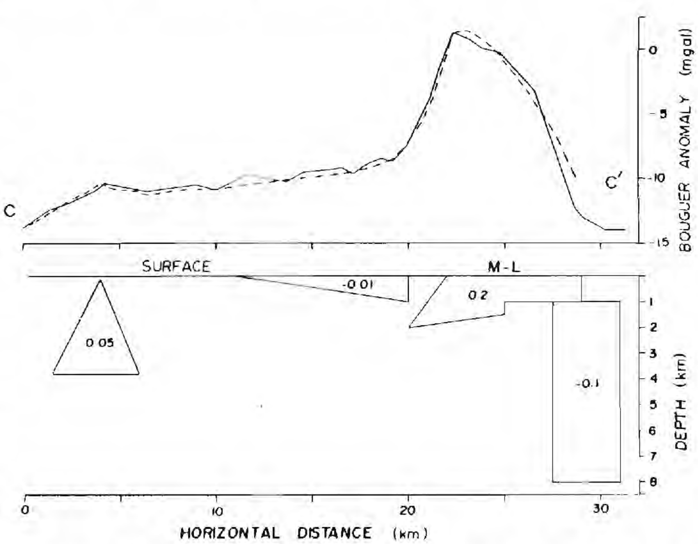

Figure 8. Comparison of observed and calculated anomalies and model for profile C–C′. Symbols as for Figure 6. From Frazier (1982).

the Middleton-Lowndesville fault has led to the erosion of the rocks equivalent to the Charlotte–Carolina Slate belts and exposure of rocks homogenized by intense regional metamorphism; (2) the Middleton-Lowndesville fault zone is a strike-slip fault of considerable displacement, bringing different terranes into juxtaposition. The second possibility must have occurred before about 350 m.y. B.P., from the paleomagnetic data presented by Ellwood (1982) in the study area and by Barton and Brown (1983) farther north; both studies showed that the Charlotte–Carolina Slate belts had similar paleopoles to the North American craton after about 350 m.y. B.P. We consider the first possibility, accretion of a microplate, as the most likely in view of the geological evidence (Williams and Hatcher, 1982) and note that the examination of detailed Bouguer gravity may be a good way to locate the sutures between such microplates. Using such a criterion, the Brevard zone is not a surface suture (Obaoye, 1979, Fig. 7), nor is the contact between the Charlotte and Carolina Slate belts.

The relationship between the surface suture of the Middleton-Lowndesville fault zone and the buried suture of the Piedmont gravity gradient with the mapped belts of the crystalline Piedmont is indicative of the tectonic style of the orogen. The surface suture corresponds with a boundary between belts, as expected, because it separates terranes of contrasting rock types and tectonic styles. The buried suture, however, does not correspond to any boundaries between the mapped crystalline belts of the Piedmont, because at least some of these belts have been thrust over the early Paleozoic North American continental margin, the site of the suture (Hatcher, 1972; Cook and others, 1979, 1981). The site of the buried suture (approximately the middle of the Piedmont gravity gradient) thus crosscuts the mapped surface belts. In the study area, it lies beneath the Inner Piedmont, but in Best and others' (1973) area to the northeast, it lies beneath the Charlotte–Carolina Slate belts. This crosscutting relationship demonstrates that the Piedmont gravity gradient cannot be interpreted as the boundary between the Charlotte and Carolina Slate belts, as proposed by Best and others (1973). The varying steepness of the Piedmont gravity gradient (Haworth and others, 1980; Long, 1979; Best and others, 1973) indicates that the depth to the buried suture is variable.

This interpretation may cause some modification of accepted models of Appalachian tectonics. It does not affect Cook and others' (1979, 1981) model, because this model considers all of the crystalline belts allochthonous and overthrust. The model of Hatcher (1972) was derived from studies close to the area considered in this work and indicates a southeastern limit of thrusting at the Kings Mountain belt, just southeast of the buried suture. If, however, our interpretation of the nature of the Piedmont gravity gradient is correct in the area studied by Best and others (1973), thrusting must extend into the Charlotte–Carolina Slate belts, because at least part of these belts covers the buried suture. More generally, if the model presented here and Hatcher's (1972) ideas are combined, one would expect the southeastern limit of thrusting to lie southeast of the buried suture and to crosscut mapped surface belts.

The modeling of Alleghenian granite bodies presented here has some bearing on theories concerning their origin. The lack of density contrast between the Elberton granite and its country rocks supports the proposal of Stormer and others (1980) that the granite was formed by anatexis of rocks close to its present position. The mapped density contrast and stock-like nature of the Danburg granite suggest that the magma was formed deeper from a parent dissimilar to the present country rocks, and that the magma was then emplaced by upward diapirlike movement, as suggested by Fullager and Butler (1979). These contrasting models for the Elberton and Danburg granites indicate that it may not be proper to group them together as Sinha and Zietz (1982) proposed.

ACKNOWLEDGMENTS

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Evidence for Cenozoic tectonism in the southwest Georgia Piedmont

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ABSTRACT

Paleocene nonmarine sediment in the Georgia Piedmont has been isolated from correlative Coastal Plain deposits by high-angle reverse faults and subsequent erosion. The reverse faults also offset surficial deposits of probable Pliocene age. The sediments, preserved north of Pine Mountain, in the vicinity of Warm Springs, Georgia, consist of (1) a lower sedimentary sequence, herein called the "Republic Mine beds," composed mainly of massive, locally bauxitic, kaolinitic clay and well-bedded, coarse to fine quartz sand; and (2) an upper sequence, herein called "surficial deposits," composed predominantly of clayey quartz sand and quartzite gravel. The compositional and textural dissimilarities between the two sequences indicate differences in provenance, depositional environment, and tectonic setting.

The orientation of the faults and the sense of fault movement near Warm Springs indicate that this area of the western Georgia Piedmont is unlike that of the tectonic regimes previously documented in the Atlantic and Gulf Coastal Plains. The orientation of some structures and the amount and rate of fault deformation are more similar to features in the Gulf Coastal tectonic province, whereas the involvement of basement rocks in fault zones and the compressional style of deformation are comparable to tectonic features described elsewhere in the eastern United States, especially in Coastal Plain sediments along the Fall Line of the Atlantic Coastal Plain.

INTRODUCTION

This paper is intended as a contribution to the accumulating data on young faulting in the eastern United States. Study of an area in the Georgia Piedmont provides additional clues to both the timing and the mode of Cenozoic deformation in the Appalachian orogen. Along the eastern seaboard of the United States, the most intensively studied areas relative to Cenozoic tectonic activity are the Piedmont and the Coastal Plain Provinces. In the Piedmont, the rocks are multiply deformed, and zones of faulting and/or ductile shearing are locally abundant; however, the general absence of datable Mesozoic and Cenozoic material usually precludes the direct demonstration of post-Paleozoic fault displacement.

In the Atlantic Coastal Plain, many faults and fault zones have been identified (York and Oliver, 1976; Howard and others, 1978; Prowell, 1983), but only a few have been studied in any detail (Mixon and Newell, 1977; Prowell and O'Connor, 1978; Dischinger, 1979). Demonstrating Mesozoic to early Cenozoic movement along such faults has been relatively straightforward; determining whether or not these faults have moved during the late Cenozoic to Holocene has been more challenging (Odom and Hatcher, 1980; Wentworth and Mergner-Keefer, 1981).

At Warm Springs, Georgia, Paleocene sediment is locally preserved as an erosional outlier within the Piedmont physiographic province (Fig. 1). The Paleocene sediments are highly deformed along their southern boundary, which is marked by a fault zone. South of the fault zone, a resistant, east-northeast–trending quartzite ridge stands as high as 200 m above the schist-

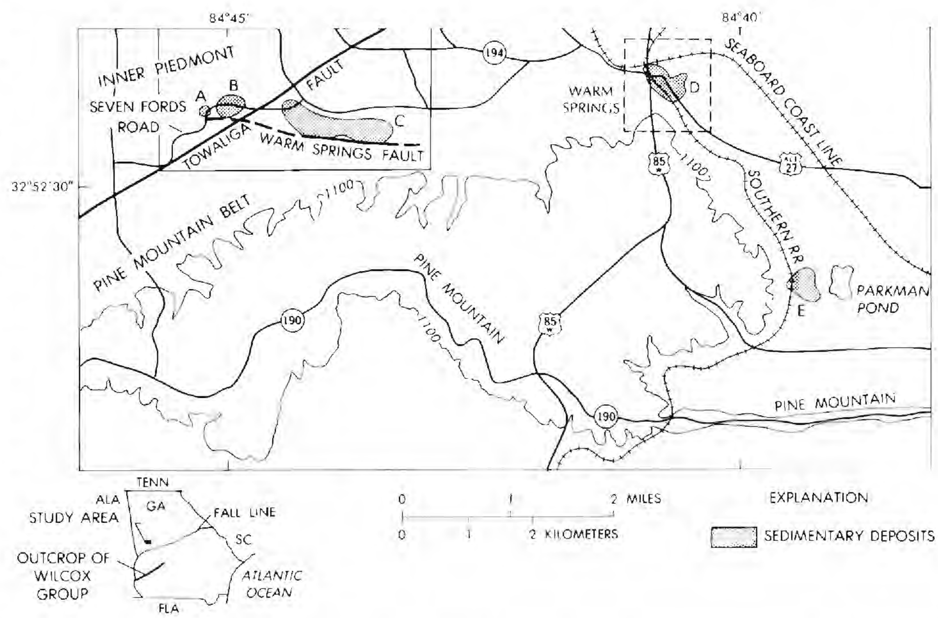

Figure 1. Location map of the Warm Springs, Georgia, study area (box in upper left; see detail in Figs. 2 and 3), showing the distribution of sedimentary deposits (stippled) relative to the Warm Springs fault, Towaliga fault, and Pine Mountain. Crest of Pine Mountain is along Georgia Route 190; 1,100-ft contour outlines this prominent topographic feature. Inset shows position of the Fall Line and Wilcox Group outcrop belt in western Georgia relative to the study area. Sediment pods are lettered A to E for reference.

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G35-648

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1. Institution and Address	2. NSF Program	3. NSF Award Number
Georgia Institute of Technology Atlanta, Georgia 30332	Geophysics	EAR78-22056
	4. Award Period From 12/15/78 To 5/31/80	5. Cumulative Award Amount $18,700

6. Project Title
Gravity Survey in the Vicinity of Proposed COCORP Traverse across the Brevard Zone near Gainesville, Georgia

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

A gravity survey has been carried out across the Brevard Zone, a major fault, in northeastern Georgia to determine whether the fault is a boundary between rocks of substantially different type and origin, and to determine subsurface structure if this is the case. 1500 readings of the acceleration due to gravity have been made at an average spacing of 1 km in a 30 km wide strip across the fault zone. Analysis of these readings indicates that there is no large anomaly associated with the Brevard Zone, and accordingly the Brevard Zone does not separate rock types of substantially different nature and origin. There is a small anomaly associated with the surface trace of the fault, probably caused by greater weathering of the fault materials relative to the surrounding country rock. These results are in agreement with seismic reflection data collected by COCORP (Consortium for Continental Reflection Profiling) in the study area, indicating that the Brevard Zone is a secondary fault associated with a deeper thrust fault.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

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The summary (about 200 words) must be self-contained and intelligible to a scientifically literate reader. Without restating the project title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent to the project being described, the following items:

- The primary objectives and scope of the project.
- The techniques or approaches used only to the degree necessary for comprehension.
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This summary will be published in an annual NSF report. Authors should also be aware that the summary may be used to answer inquiries by nonscientists as to the nature and significance of the research. Scientific jargon and abbreviations should be avoided.

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Items in Part III may, but need not, be submitted with this Final Project Report. Place a check mark in the appropriate block next to each item to indicate the status of your submission.

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e. Provide a technical summary of the activities and results. The information supplied in proposals for further support, updated as necessary, may be used to fulfill this requirement.
f. Include any additional material, either specifically required in the award instrument (e.g. special technical reports or products such as films, books, studies) or which you consider would be useful to the Foundation.

Attachment 1. Abstract of Thesis

Interpretation of Detailed Gravity Traverses

Across Northeastern Georgia

M. O. Obaoye

89 Pages

Directed by Dr. A. M. Dainty

In North Georgia, the regions of large positive Bouguer gravity anomalies are associated with either mafic or ultramafic intrusive plutons. In some cases the massive intrusives are gabbroic in composition. Mafic to ultramafic rocks are often associated with economic mineral depcsits such as chromite, ilmenite, apatite, platinum and nickel-sulfides. Such bodies are located in the Piedmont Province and under Coastal Plain sediments. Other positive Bouguer gravity anomalies in the Piedmont Province are associated with dense metamorphic rocks such as gneiss and amphibolite. Some low amplitude positive Bouguer gravity anomalies in the Brevard zone are thought to be due to variation in subsurface rock types not observed on the surface.

The negative regional Bouguer gravity anomalies which generally become more negative toward the northwest are caused by progressive deepening of the Moho, i.e., because of compensation at the base of the crust for the general increase in elevation. Other negative Bouguer gravity anomalies are associated with buried Triassic basins beneath the Coastal Plain sediments. These basins consist of low density material and are marked by normal faults on each edge. Much less prominent gravity lows are associated with granitic plutons.

The Bel Air Fault Zone does not have any appreciable gravity anomalies associated with it either because the throw of the fault (maximum of 30 meters) is too small to reflect in the gravity anomalies, or the data point spacing is not close enough to indicate any anomalies associated with it.

The Brevard Zone is also not characterized by any appreciable gravity anomalies. The gravity low discovered across the Brevard Zone is only a local one within the Brevard Zone and it is thought to be caused by a variation in rock type; that is, a lateral change in the densities of the rock types from a higher density rock to a lower density one.

Attachment 2. Scientific Collaborators

Coinvestigator:	Dr. Leland T. Long, Associate Professor
Research Assistants:	Michael O. Obaoye, graduate student
	Christopher S. Howard, graduate student
	Sandra A. Gould, Technical Assistant

Attachment 3. Technical Description of Project and Results

Gravity Survey in the Vicinity of Proposed COCORP Traverse
Across the Brevard Zone near Gainesville, Georgia

Final Technical Report

Prepared by

Anton M. Dainty
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

August, 1980

Introduction

The purpose of this study was to investigate the Brevard Zone along Georgia line 1 of the COCORP Appalachian Traverse using gravity data. A primary objective was to determine whether the Brevard Zone separated or offset rocks of substantial density contrasts and to determine any such offset. A secondary objective was to determine whether any gravity anomaly was caused by the Brevard Zone or any associated structure and to determine the cause of any such anomaly. This study was undertaken because of the prominence of the Brevard Zone in many published interpretations of Appalachian tectonics (e.g. Rankin, 1975, considered the Brevard Zone to be a suture).

Data and Data Reduction

1470 readings of the acceleration due to gravity were taken in the survey area using a Worden Educator gravity meter and a Lacoste Romberg gravity meter. Elevation was taken from United States Geological Survey Topographic Sheets, 1:24,000 series. The average spacing between points is 1 km, but a dense spacing of 1000-2000 feet was used along the COCORP Georgia Line 1 and in the central region of the study area, while a 2 km spacing was used in peripheral regions. Readings were reduced to Observed Gravity and Free Air and Simple Bouguer anomaly using the 1931 Standard Gravity Formula and a reduction density of 2.67 gm/cc for the Bouguer reduction. Figure 1 is a map of the Simple Bouguer anomaly values. The estimated error in the Free Air and Simple Bouguer anomaly is ±0.4 mgals, and is mainly due to uncertainty in the elevation. A larger scale map (1:125,000) and individual gravity values, either as a listing or as card images on computer tape, are available from the author on request. The card images are written in the Department of

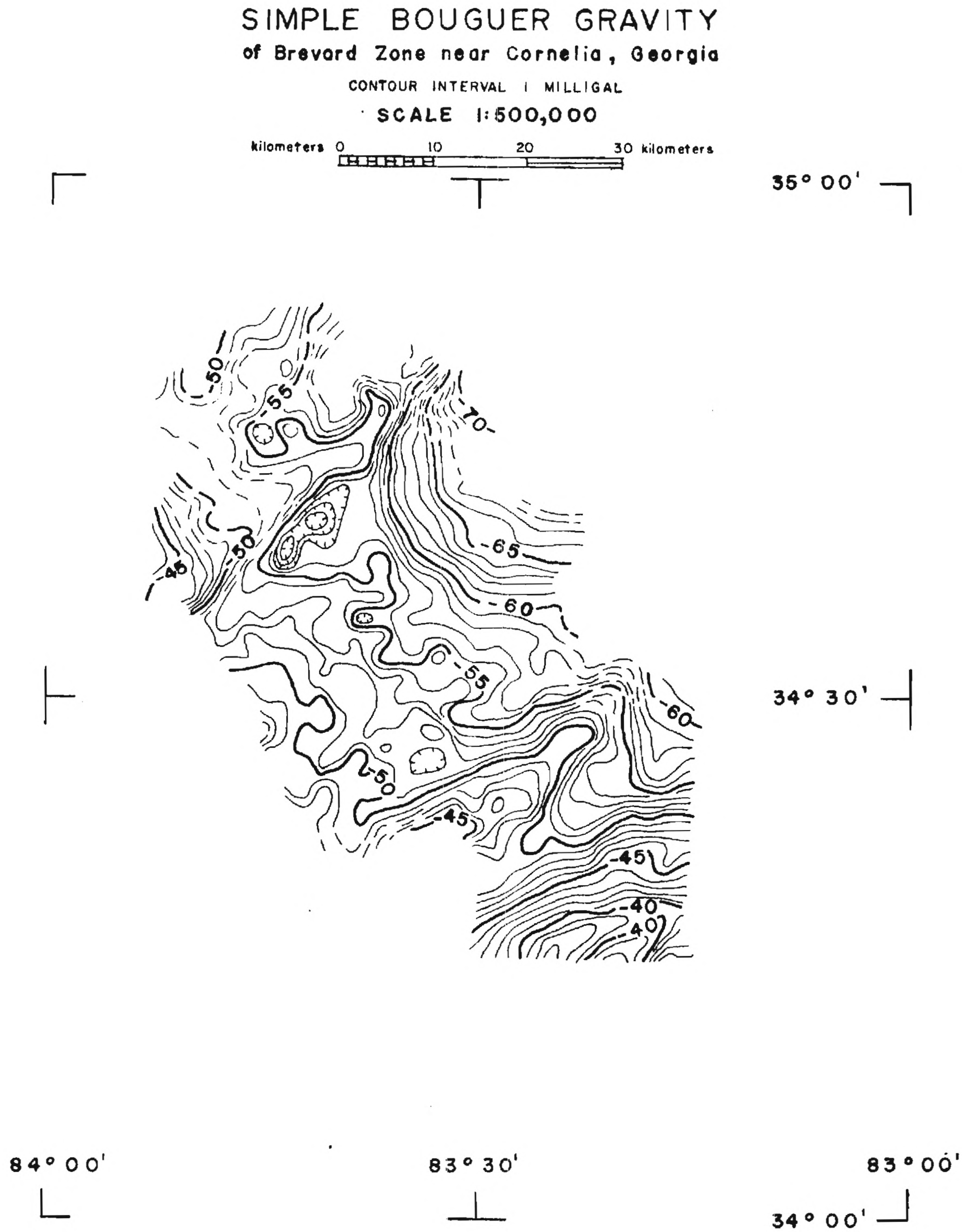

Figure 1. Map of Simple Bouguer Gravity in the study area. Note: This figure has been reduced.

Defence Gravity Services Gravity Station Data Card Format, effective 1 July 1973.

Discussion of the Simple Bouguer Anomalies

Figure 2 is a map of the Simple Bouguer anomaly field with geological formations of interest superposed. The COCORP Georgia Line 1 is also shown in Figure 2. Regional features seen on Figure 2 include a strong gravity gradient in the southeastern portion of the map and a gradient towards an intense gravity low in the northeastern corner of the map. The gradient in the southeastern part is a section of the Piedmont Gravity Gradient that runs from Georgia to Virginia and is associated with crustal thinning from northwest to southeast (Long, 1979). Recent structural interpretations based on COCORP data (Cook et al., 1979), indicate that it is unlikely this crustal thinning is associated with the Brevard Zone. The low to the northeast is part of an intense low associated with the highest part of the Appalachian mountains running from Georgia to Pennsylvania, and is presumably due to crustal thickening.

More local features can also be seen in Figure 2. The Brevard Zone of cataclasis is marked, as well as the Dahlonega Shear Zone. A positive Bouguer anomaly of $\sim$ 5 mgals is associated with the Dahlonega Shear Zone, probably caused by the metamorphosed mafics present in the Zone. A small negative Bouguer anomaly of 0-2 mgals is associated with the surface trace of the Brevard Zone. Figure 3 shows a profile along the COCORP Georgia Line 1, crossing the Brevard Zone. There does not appear to be a correlation of topography and Bouguer anomaly, thus the Bouguer anomalies must be due to subsurface causes. Anomalies within the Brevard Zone fluctuate rapidly, suggesting a very near surface

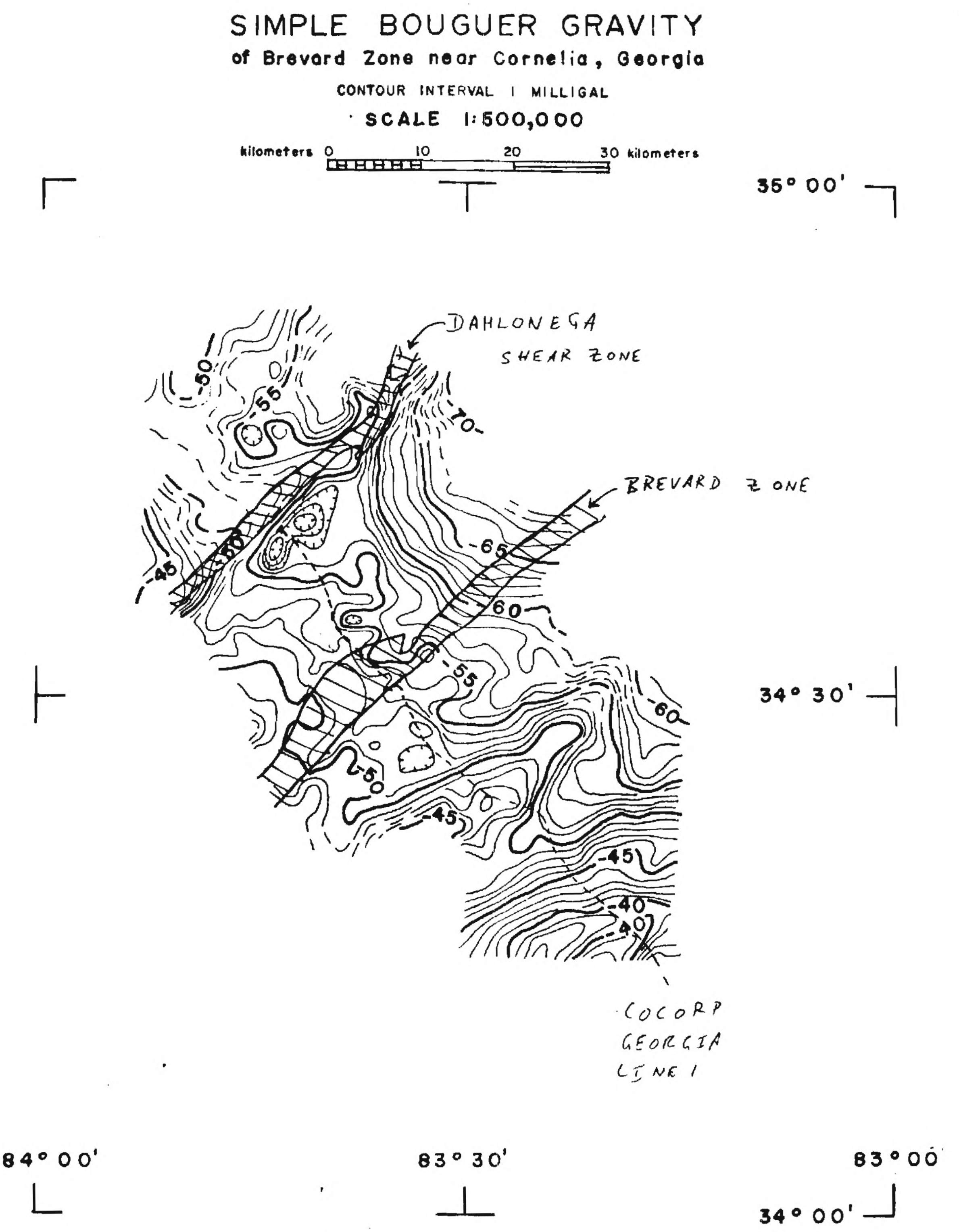

Figure 2. Map of Simple Bouguer Gravity with geologic correlations. Note: This figure has been reduced.

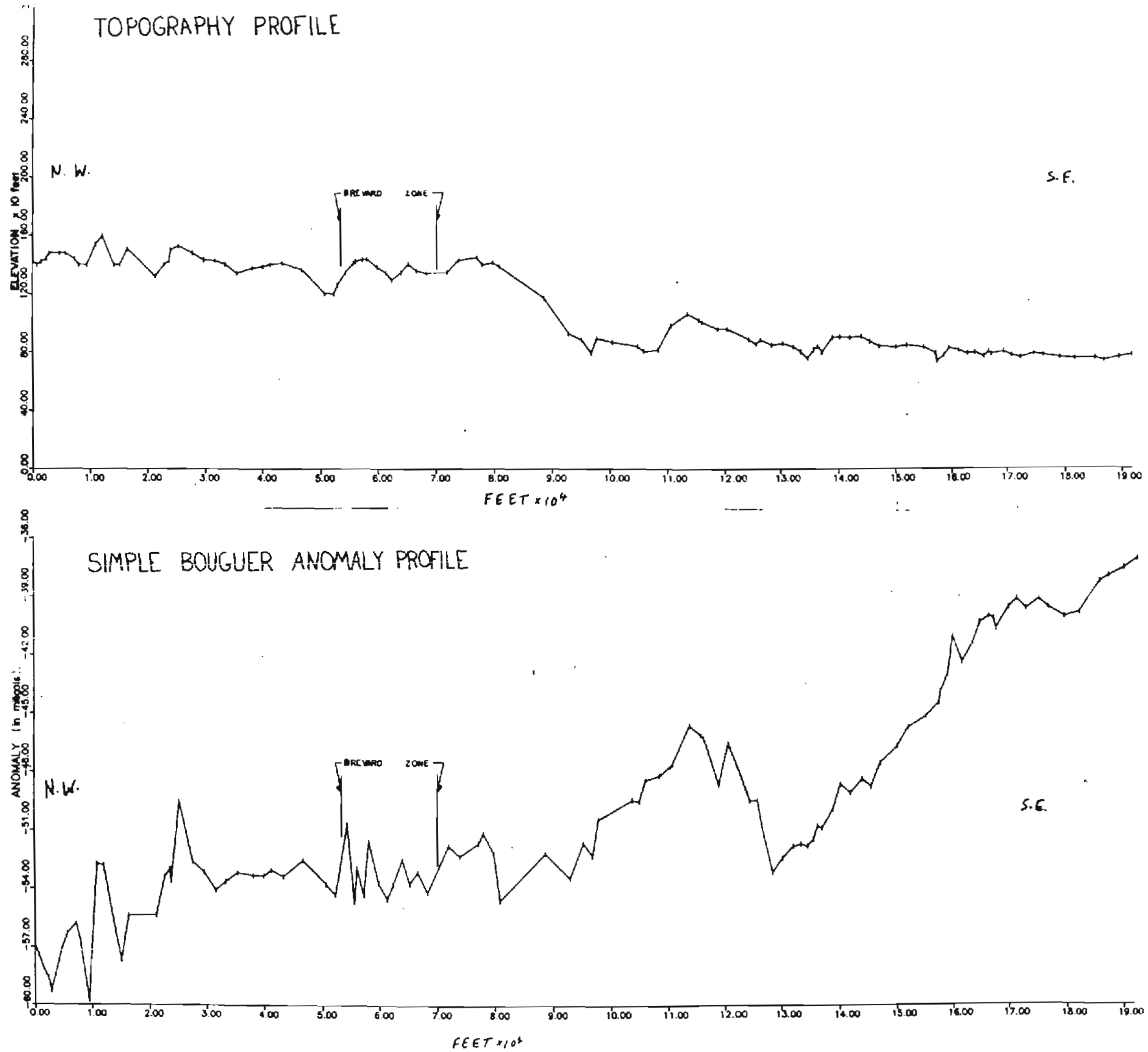

Figure 3. Profile of Simple Bouguer Gravity and topography along COCORP Georgia Line 1.

source. The most likely explanation for the anomaly associated with the Brevard Zone is weathering to a greater depth relative to surrounding areas. Support for this hypothesis comes from the influence the Brevard Zone has on the course of the Chattahoochee River - this river is deflected to run southwest along the Brevard Zone over most of its length in Northern Georgia, and is the only major river to run in this direction. The proposed greater weathering depth in probably due to the fine grained nature of the rocks in the zone of cataclasis leading to greater chemical weathering. If a density contrast of 1 cm/cc is assumed between fresh and weathered rock, the observed anomaly can be explained by 0-50 m of extra weathered material in the Brevard Zone. This is entirely reasonable for this area. Part of the weathered material may be in the form of alluvium.

Apart from this minor, near surface anomaly, there is no appreciable anomaly associated with the Brevard Zone, indicating that the Brevard Zone does not offset and/or separate rocks of different density. Surface rocks in the study area are metamorphosed to a greater or lesser degree, and are frequently not differentiated on different sides of the Brevard Zone on the Geologic Map of Georgia (1976), even though the Brevard Zone is considered to be the boundary between two major divisions of the Appalachians, the Blue Ridge and the Inner Piedmont. A subsurface interpretation of the Brevard Zone based on COCORP reflection data (Cook et al., 1979) indicates that it is a splay off a sole thrust underlying both the Blue Ridge and the Inner Piedmont, rather than a primary structure. Our conclusions are compatible with this interpretation.

In addition to the anomalies discussed above, parts of anomalies superposed on the Piedmont Gravity Gradient are seen in the southeast portions of Figures 1, 2 and 3. These anomalies are believed to be associated with an area of metamorphosed mafic rocks in this area.

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